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Charcoal Manufacturing

State of the Art

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16. ABSTRACT

This document reviews the state of the art of air emissions from charcoal manufacture. The composition, quality, and rate of emissions, and their environmental effects are described. Charcoal is the solid material remaining after the pyrolysis of carbonaceous materials, primarily hardwoods. It is produced in both batch and continuous facilities and then briquetted. During the manufacturing process, emissions of particulate, carbon monoxide, hydrocarbons, and nitrogen oxides are released. To evaluate the hazard potential of representative sources defined for batch kilns, continuous furnaces, and briquetting operations, source severity was defined as the ratio of the time-averaged maximum ground level pollutant concentration to a hazard factor. For criteria pollutants, the hazard factor is the ambient air quality standard; for noncriteria pollutants, it is a reduced TLV. Source severities range for controlled batch kilns from 0.016 to 3.7, for continuous furnaces from 0.0097 to 4.6, and for briquetting operations from 0.27 to 1.6. Batch kilns do not typically have emission control devices; however, some kilns utilize afterburners. Continuous furnaces are believed to use some level of afterburning to reduce particulate carbon monoxides, and hydrocarbons. Briquetting operations control particulate emissions via centrifugal collection or fabric filtration.

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SOURCE ASSESSMENT: CHARCOAL MANUFACTURING
State of the Art

by

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Contract No. 68-02-1874

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DISCLAIMER

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains information on air emissions from the charcoal manufacturing industry. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from charcoal manufacture. Further information on this subject may be obtained from the Food and Wood Products Branch, Industrial Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for investing tax dollars in programs to develop control technology for a large number of operations (more than 500) in the chemical industries. As in any technical program, the first question to answer is, "Where are the unsolved problems?" This is a determination which should not be made on superficial information; consequently, each of the industries is being evaluated in detail to determine if there is, in EPA's judgment, sufficient environmental risk associated with the process to invest in the development of control technology.

Monsanto Research Corporation has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as Program Manager in this overall program entitled, "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer. Reports prepared in the Source Assessment Program are of two types: Source Assessment Documents and State-of-the-Art Reports. The major difference between the two is the quantity and quality (reliability) of the data reported.

Source Assessment Documents contain data on emissions from specific industries gathered from literature, government agencies, and cooperating companies. Emissions sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source emissions. The intent of these documents is to provide all of the information necessary for IERL to decide whether emissions reduction is required.

State-of-the-Art Reports contain information on emissions from specific industries gathered from literature, government agencies, and cooperating companies. However, no emissions sampling of industries is conducted by the contractor in a state-of-the-art study. Data quality available may be poor and, if so, this is called out in the report. The intent of the report is to provide an overview of the industry and to indicate where data are lacking. Results of such studies aid EPA in deciding if further, indepth study of the industry is warranted. Such reports have potential utility to government, industry, and other researchers having specific needs and interests.

This state-of-the-art study was undertaken to provide information on air emissions from charcoal manufacturing. The study was initiated by IERL-RTP in July 1975 with Dr. R. A. Venezia of the Industrial Processes Division at RTP serving as EPA Task Officer. Project responsibility was transferred to IERL-Cincinnati in October 1975, and Dr. H. Kirk Willard of the Food and Wood Products Branch of the Industrial Pollution Control Division served as EPA Task Officer until the study was completed.

ABSTRACT

This document reviews the state of the art of charcoal manufacture. Information collected from literature, government agencies, and industrial sources was used to evaluate process chemistry, process technology, industry population and geographical distribution, airborne emissions and environmental effects, control technology, and future trends in the industry.

Charcoal is the solid material remaining following the pyrolysis of carbonaceous materials, primarily hardwoods. It is produced in both batch and continuous facilities and then briquetted. In 1975 an estimated 590,000 metric tons of charcoal were produced to satisfy its primary use as a recreational fuel. Charcoal production is concentrated in the southeastern quadrant of the United States, with Missouri dominating production.

Emissions estimates were made for the following species: particulate, carbon monoxide, methanol, methane, hydrogen, polycyclic organic materials, nitrogen oxides, and other gases. For criteria pollutants, controlled emissions from charcoal manufacture are estimated to range from 0.03% to 0.05% of the total national emissions of these pollutants. Source severity (the ratio of a calculated maximum ground level concentration from a representative source to a defined allowable concentration) values for controlled emissions from batch kilns range from 0.016 to 3.7, for continuous furnaces from 0.0097 to 4.6, and for briquetting operations from 0.27 to 1.6. The affected population for charcoal manufacture in controlled facilities ranges from 0 persons to 247 persons.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 1975 to October 1977.

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ABBREVIATIONS AND SYMBOLS

A_R -- $Q/ac\pi u$

a,b,c,d,f -- constants (Appendix B)

B_R -- $-H^2/2c^2$

e -- 2.72

F -- hazard factor; for criteria emissions, F is the ambient air quality standard; for noncriteria emissions, F is a reduced TLV

H -- emission height

h -- stack height

Q -- emission rate

S -- source severity

TLV -- threshold limit value

t_o -- short-term averaging time (3 min)

t -- averaging time

u -- wind speed

$\bar{u}$ -- average wind speed

x -- downwind dispersion distance from source of emission release

y -- horizontal distance from centerline of dispersion

π -- 3.14

σ_y -- standard deviation of horizontal dispersion

σ_z -- standard deviation of vertical dispersion

χ -- downwind ground level concentration at reference coordinate (x, y)

$\bar{\chi}$ -- average ground level concentration

χ_{max} -- maximum ground level concentration of a pollutant

$\bar{\chi}_{max}$ -- time-averaged maximum ground level concentration of a pollutant

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	To	Multiply by
Degree Celsius (°C)	Degree Fahrenheit	$t_F^\circ = 1.8\ t_C^\circ + 32$
Degree Kelvin (K)	Degree Celsius	$t_C^\circ = t_K^\circ - 273.15$
Joule (J)	British thermal unit	9.479×10^{-4}
Kilogram (kg)	Pound-mass (lb-mass avoirdupois)	2.205
Kilogram (kg)	Ton (short, 2,000 lb-mass)	1.102×10^{-3}
Kilometer^2 (km^2)	Mile^2	3.860×10^{-1}
Meter (m)	Foot	3.281
Meter^3 (m^3)	Foot^3	3.531×10^1
Metric ton	Pound-mass	2.205×10^3
Metric ton	Ton (short, 2,000 lb-mass)	1.102

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Giga	G	10^9	1 GJ = 1×10^9 joules
Kilo	k	10^3	1 kg = 1×10^3 grams
Mega	M	10^6	1 MJ = 1×10^6 joules
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter

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[a] Standard for Metric Practice. ANSI/ASTM Designation: E 380-76$^\epsilon$, IEEE std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.

SECTION 1

INTRODUCTION

Although the primary current use of charcoal is as a recreational cooking fuel, its manufacture has a long and interesting history in the United States. In the Colonial period, charcoal was produced as a fuel for iron smelting. As metallurgical charcoal requirements peaked toward the end of the 19th century, byproduct recovery of acetic acid and methanol for the synthetic organic chemical industry became important to the growth of charcoal production. Production of acetic acid and methanol stimulated growth into the 20th century with charcoal becoming the byproduct until more efficient and less expensive acetic acid and methanol synthesis routes were commercialized. Subsequently, charcoal production declined until all acetic acid and methanol recovery plants had ceased operation. Then charcoal once again became the primary product. Demand for charcoal as a recreational fuel has boosted production to an estimated 590,000 metric tons[a] annually, greater than the previous peak production of 500,000 metric tons in 1909.

Charcoal manufacturing is not a homogeneous industry. It uses a variety of raw materials and operating practices. However, production can be generally classified into either batch or continuous operations. Batch units are small, manually loaded and unloaded kilns producing typically 16 metric tons of charcoal during a 3-wk cycle, while continuous units produce an average of 2.5 metric tons/hr of charcoal. Both of these processes, as well as the general process chemistry, are described in detail.

This report discusses air emissions from the manufacture of charcoal. Emission points within the manufacturing process are identified, types and quantities of emissions are delineated, and characteristics of air pollutants are listed. State and national emissions of criteria pollutants from the charcoal industry are compared to total state and national emissions from all sources. The maximum average ground level concentrations of emissions from typical charcoal plants are compared to a corresponding ambient air quality. The effect of control technology is also discussed. Possible future trends in the industry are delineated.

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[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory pages of this report.

SECTION 2

SUMMARY

Charcoal is manufactured by the pyrolysis of carbonaceous materials, primarily hardwoods, in batch kilns or continuous furnaces. This document examines air emissions from the basic manufacturing processes and from the formation of charcoal briquets. The manufacture of activated carbon is not included because it represents a declining fraction of total charcoal plus activated carbon production.

Estimated 1975 production of charcoal was 590,000 metric tons with an estimated distribution of 55% manufactured in continuous furnaces and the remaining 45% manufactured in batch kilns. On a number basis, this production represents an estimated 1,330 batch kilns and 16 continuous furnaces. There are also an estimated 32 charcoal briquetting plants in the United States. Charcoal production is located primarily in the southeastern quadrant of the United States. Missouri produces an estimated 45% of national production.

During the manufacturing process, emissions of particulate, carbon monoxide, hydrocarbons, hydrogen, and nitrogen oxides are released to the atmosphere. Table 1 presents the range in uncontrolled emission factors for these species, estimated national emissions from the charcoal industry based on the current application of control technology, and the percent contribution of charcoal production to total national criteria emissions from all sources. Ranges are reported for emission factors because of the poor quality of the input data. Table 2 shows the estimated contribution of charcoal manufacture to the emission of criteria pollutants on a state-by-state basis for states in which charcoal production was identified.

For use in assessing the environmental impact of charcoal manufacturing, representative emission sources were defined for batch kilns, continuous furnaces, and briquetting operations. A representative batch kiln produces approximately 200 metric tons of charcoal annually, and there are 12 kilns at a typical charcoal batch plant. Every kiln has eight emission stacks each approximately 4.6 m high. A representative continuous furnace is defined as having an average annual production rate of approximately 20,000 metric tons. Each furnace has one emission point a stack 21 m high. An average briquetting facility processes

TABLE 1. MASS EMISSIONS FROM CHARCOAL MANUFACTURE

Emission species	Uncontrolled emission factor, g/kg: Charcoal manufacture	Uncontrolled emission factor, g/kg: Briquetting	Total annual controlled emissions in 1975, metric tons[a]	Percent of national emissions from all sources
Particulate[b]	28 to 40	7 to 42	6.6×10^3 to 9.3×10^4	0.04 to 0.5
Carbon monoxide	160 to 179	–[c]	3.6×10^4 to 4.0×10^4	0.04 to 0.04[d]
Methanol	67 to 76	–[c]	1.5×10^4 to 1.7×10^4	
Acetic acid	102 to 116	–[c]	2.3×10^4 to 2.6×10^4	0.2 to 0.2[d,e]
Other gases[f]	7 to 60	–[c]	1.6×10^3 to 1.4×10^4	
Methane	44 to 57	–[c]	9.9×10^3 to 1.3×10^4	–[g]
Hydrogen	0.5 to 2	–[c]	1.2×10^2 to 4.5×10^2	–[g]
Nitrogen oxides	12	–[c]	7.3 to 10^3	0.03
Polycyclic organic materials	0.004	–[c]	0.90	–[g]

[a] Controlled emissions were determined based on the following assumptions: 25% of batch kilns have 85% efficient afterburning, 100% of continuous furnaces have 95% efficient afterburning, and 100% of briquetting plants have 95% efficient particulate control.

[b] Includes tar, oil, and pyroacids.

[c] No information available.

[d] The calculation rounded to one significant figure yields the same number for high and low end of the range.

[e] Methanol, acetic acid, and other gases summed and compared to national hydrocarbon emissions.

[f] Includes compounds identified in the literature as "higher hydrocarbons" (assumed to be non-methane noncondensibles), ethane, formaldehyde, and unsaturated hydrocarbons (e.g., ethylene).

[g] Not applicable.

TABLE 2. ESTIMATED CONTRIBUTION OF CHARCOAL PRODUCTION TO STATE TOTAL CRITERIA EMISSIONS

State	Percent of emissions: Particulate	Carbon monoxide	Hydrocarbons[a]	Nitrogen oxides
Arkansas	<1 to 6	<1	2 to 3	<1
California	<1	<1	<1	<1
Maryland	<1	<1	<1	<1
Minnesota	<1	<1	<1	<1
Mississippi	<1 to 2	<1	<1 to 1	<1
Missouri	1 to 21	<1	5 to 6	<1
North Dakota	<1 to 8	<1	5 to 6	<1
Ohio	<1	<1	<1	<1
Oklahoma	<1 to 2	<1	<1	<1
South Carolina	<1 to 1	<1	<1	<1
Tennessee	<1	<1	<1	<1
Virginia	<1 to 1	<1	<1 to 1	<1
Wisconsin	<1	<1	<1	<1

[a] Based on the summation of methanol, acetic acid, polycyclic organic materials, and other gases.

approximately 18,000 metric tons of briquets annually and has a 7.6 m emission height.

To evaluate the hazard potential of the representative sources, the source severity, S, was defined as the ratio of the time-averaged maximum ground level concentration of a pollutant, $\overline{\chi}max$, determined using Gaussian plume dispersion methodology, to a hazard factor, F. For criteria emissions, F is the ambient air quality standard. For noncriteria emissions, F is a reduced TLV®. Values for S, shown in Table 3, are based on both controlled and uncontrolled emissions.

TABLE 3. SOURCE SEVERITIES FOR REPRESENTATIVE CHARCOAL MANUFACTURING PLANTS

	Source severity, S[a]					
	Batch kiln		Continuous furnace		Briquetting	
Emission species	Uncontrolled	Controlled[b]	Uncontrolled	Controlled[c]	Uncontrolled	Controlled[c]
Particulate[d]	1.7 to 25	0.26 to 3.7	3.0 to 44	0.15 to 2.2	5.4 to 32	0.27 to 1.6
Carbon monoxide	0.11 to 0.12	0.016 to 0.018	0.19 to 0.22	0.0097 to 0.011	–[e]	–[e]
Methanol	1.2 to 1.4	0.19 to 0.21	2.2 to 2.5	0.11 to 0.12	–[e]	–[e]
Acetic acid	20 to 23	3.0 to 3.4	35 to 39	1.7 to 2.0	–[e]	–[e]
Other gases[f]	1.0 to 8.5	0.2 to 1.3	1.7 to 15	0.09 to 0.8	–[e]	–[e]
Methane	–[g]	–[g]	–[g]	–[g]	–[e]	–[e]
Hydrogen	–[g]	–[g]	–[g]	–[g]	–[e]	–[e]
Nitrogen oxides	2.8	3.0	4.2	4.6	–[e]	–[e]
Polycyclic organic materials	19	2.9	34	1.7	–[e]	–[e]

[a] Emissions assured constant over period of emission, batch 2,971 hr/yr, continuous and briquetting 8,000 hr/yr. Also assumed one emission point per source.

[b] Based on 85% control efficiency for particulate, carbon monoxide, and hydrocarbons.

[c] Based on 95% control efficiency for particulate, carbon monoxide, and hydrocarbons.

[d] Includes tar, oil, and pyroacids.

[e] No information.

[f] Includes compounds identified in the literature as "higher hydrocarbons" (assumed to be nonmethane noncondensibles), ethane, formaldehyde, and unsaturated hydrocarbons (e.g., ethylene).

[g] Methane and hydrogen are simple asphyxiants, have no TLV or F and therefore no S.

Affected population is defined as the population around a representative plant that is exposed to an average ground level concentration ($\overline{\chi}$) for which $\overline{\chi}/F$ is either greater than 0.1 or greater than 1.0. Among the emissions from charcoal manufacture, the largest population is affected by nitrogen oxides, followed in decreasing order by particulate, acetic acid, polycyclic organic materials, other gases, and methanol. For $\overline{\chi}/F$ greater than 1.0, the affected populations range from 0 to 11 persons, for $\overline{\chi}/F$ greater than 0.1, the range is from 0 to 247 persons.

Batch kilns do not typically have emission control devices. However, some kilns utilize afterburners to reduce emissions. Continuous furnace charcoal production facilities are all believed to use some level of afterburning to reduce emissions. Afterburning is estimated to reduce emissions of particulates, carbon monoxide, and hydrocarbons by a minimum of 80%. Briquetting operations can control particulate emissions with centrifugal collection (65% control) or fabric filtration (99% control).

The future growth in charcoal production is projected to be approximately 4%/yr. This will result in a 22% growth in production over the 5-yr period from 1975 to 1980, and, if emission control efficiency and application remain constant, an increase in emissions of 22% over the same period.

SECTION 3

SOURCE DESCRIPTION

SOURCE DEFINITION

Charcoal is the solid carbonaceous residue remaining following the pyrolysis (carbonization or destructive distillation) of carbonaceous raw materials. Raw materials can be almost any carbonaceous material of either animal, vegetable, or mineral origin, but medium to dense hardwoods such as beech, birch, hard maple, hickory, and oaks are the principal commercial raw materials (92% in 1961) (1, 2). Other raw materials include softwoods (primarily longleaf and slash pine), nutshells, fruit pits, coal, vegetable wastes, and papermill residues (1, 3-5).

Charcoal is used primarily as a recreational fuel, but in some instances its manufacture may be considered as a solid waste disposal technique. As noted above, many raw materials for charcoal manufacture are wastes, and charcoal manufacture is also used as

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(1) Toole, A. W., P. H. Lane, C. Arbogast, Jr., W. R. Smith, R. Peter, G. Locke, E. Beglinger, and E. C. O. Erickson. Charcoal Production, Marketing, and Use. Forest Products Laboratory Report No. 2213, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin; Southeastern Forest Experiment Station, Asheville, North Carolina; and Lake States Forest Experiment Station, St. Paul, Minnesota, July 1961. 137 pp.

(2) Doying, E. G. Activated Carbon. In: Kirk-Othmer Encyclopedia of Chemical Technology, Volume 4. John Wiley & Sons, Inc., New York, New York, 1964. pp. 149-158.

(3) Panshin, A. J., E. S. Harrar, J. S. Bethel, and W. J. Baker. Forest Products, Their Sources, Production, and Utilization. McGraw-Hill Book Company, Inc., New York, New York, 1962. pp. 404-424.

(4) Stamm, A. J., and E. E. Harris. Chemical Processing of Wood. Chemical Publishing Co., Inc., New York, New York, 1953. pp. 440-468.

(5) Nut Shells and Pits Reduced to Profit. Actual Specifying Engineer, 26(4):91-92, 1971.

an outlet for disposal of forest management refuse (6, 7). In fact, charcoal manufacture has been responsible for the elimination of some teepee burners used for disposal of wood waste (personal communication, Bruce L. Winter, Clorox Company, 26 August 1977).

Charcoal is produced batchwise or continuously by heating the raw materials in kilns or furnaces with limited quantities of air. Product charcoal is then either sold as raw bulk charcoal, made into briquets, or activated by further heat treatment.

In 1975 an estimated 80% to 90% of charcoal was briquetted (personal communication, R. Massengale, Missouri Conservation Department, 31 July 1975), an increase from 69% in 1961 (8). Activated carbon production comprised 14% of charcoal briquet and activated carbon production in 1972, a decline from 18% in 1967 (9, 10). Therefore, this assessment of charcoal manufacture includes the carbonization and the briquetting processes but not production of activated carbon.

PROCESS DESCRIPTION

Chemistry

The elemental composition of wood, regardless of species, is approximately 50% carbon, 6% hydrogen, and 44% oxygen on an ash-free, moisture-free basis; the approximate chemical formula is $C_{42}H_{60}O_{28}$ (11). Nitrogen, sulfur, and ash content are all

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(6) Hamilton, L. S., and F. Fontana. Arnot Forest's Portable Steel Charcoal Kiln. Northern Logger, 18(1):19, 35, 1969.

(7) Boldt, C. E., and C. Arbogast, Jr. Charcoal Kiln Operation for Improved Timber Stands. Forest Products Journal, 10(1): 42-44, 1960.

(8) Charcoal and Charcoal Briquette Production in the United States, 1961. U.S. Department of Agriculture, Washington, D.C., February 1963. 33 pp.

(9) Gum and Wood Chemicals, SIC 2861, Preliminary Report, 1972 Census of Manufacturers, Industry Series. MC72(P)-28-F-1, U.S. Department of Commerce, Washington, D.C., January 1974. 6 pp.

(10) Industrial Inorganic Chemicals Not Elsewhere Classified, SIC 2819, Preliminary Report, 1972 Census of Manufacturers, Industry Series. MC72(P)-28A-4, U.S. Department of Commerce, Washington, D.C., December 1973. 14 pp.

(11) Rieck, H. G., Jr., E. G. Locke, and E. Tower. Charcoal, Industrial Fuel from Controlled Pyrolysis of Sawmill Wastes. The Timberman, 46(2):49-54, 1944.

typically below 1%, while moisture content on a dry wood basis for hardwoods ranges from 40% to 99% (normally 50%) (4, 12-14).

Hardwood charcoal is manufactured by a four-step pyrolysis process. Heat is applied to the wood, and as the temperature rises to 100°C, water and highly volatile hydrocarbons are distilled off. The wood temperature remains at approximately 100°C until the moisture content of the wood has been removed, at which time the volume of distillate production declines and the wood temperature begins to climb. During the next stage, the wood temperature rises with heat input to approximately 275°C, and hydrocarbon distillate yield increases. As the third stage begins in the vicinity of 275°C, external application of heat is no longer required since the carbonization reactions become exothermic. During this stage, the wood temperature rises to 350°C, and the bulk of hydrocarbon distillates are produced. At approximately 350°C, exothermic pyrolysis ends, and during the final stage, heat is again applied, raising the wood temperature to 400°C to 500°C to remove more of the less volatile, tarry materials from the product charcoal (3, 11).

Wood, being a complex organic material, yields a wide variety of products upon the application of heat. A generalization of the pyrolysis of wood can be expressed as follows:

$$\underset{\text{(wood)}}{2C_{42}H_{60}O_{28}} \longrightarrow \underset{\text{(charcoal)}}{3C_{16}H_{10}O_2} + \underset{\text{(water)}}{28H_2O} + \underset{\substack{\text{(carbon}\\\text{dioxide)}}}{5CO_2} + \underset{\substack{\text{(carbon}\\\text{monoxide)}}}{3CO} + \underset{\substack{\text{(acetic}\\\text{acid)}}}{2C_2H_4O_2} + \underset{\text{(methanol)}}{CH_3OH} + \underset{\text{(wood tar)}}{C_{23}H_{22}O_4} \qquad (1)$$

This reaction is exothermic, and the heat evolved is approximately 6% of the total heat of combustion of the wood (11).

Products of charcoal manufacture are divided into four categories: charcoal, noncondensible gases, pyroligneous liquor, and insoluble tars. Products and product distribution are variable depending on raw materials and carbonization parameters. Consequently, numbers presented as product yields are ranges or typical values. A laboratory carbonization of dry hard maple gives an indication of the relative breakdown of products: 31% charcoal, 25%

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(12) Kanury, A. M., and P. L. Blackshear, Jr. Some Considerations Pertaining to the Problem of Wood-Burning. Combustion Science and Technology, 1(5):339-355, 1970.

(13) Air Pollution Control for Missouri Charcoal Kilns. Sverdrup & Parcel and Associates, Inc. Prepared for The Missouri Air Conservation Commission, February 1971. 29 pp.

(14) Gallagher, F. P. Utilization of Off Gases from Herreshoff-Furnace Charcoal Production. In: Proceedings of the 11th Biennial Conference of the Institute for Briquetting and Agglomeration, Sun Valley, Idaho, 1969. pp. 27-29.

noncondensible gases, 39% pyroligneous liquor, and 5% insoluble tars (15).

Charcoal is the solid carbonaceous residue remaining following the pyrolysis of wood. It is a complex combination of carbon and hydrocarbons with composition dependent on distillation temperature as indicated in Table 4. Charcoal produced at 400°C has a volatile content of 15% to 25%. The volatile fraction in the product charcoal decreases with increasing distillation temperature as evidenced by the declining charcoal yields with increasing temperature presented in Table 4.

TABLE 4. AMOUNT AND COMPOSITION OF CHARCOAL PRODUCED AT DIFFERENT MAXIMUM TEMPERATURES (4)

Distillation temperature, °C	Composition of charcoal, %			Yield of charcoal on the dry weight of wood, %
	Carbon	Hydrogen	Oxygen	
200	52.3	6.3	41.4	91.8
250	70.6	5.2	24.2	65.2
300	73.2	4.9	21.9	51.4
400	77.7	4.5	18.1	40.6
500	89.2	3.1	6.7	31.0
600	92.2	2.6	5.2	29.1
700	92.8	2.4	4.8	27.8
800	95.7	1.0	3.3	26.7
900	96.1	0.7	3.2	26.6
1,000	96.6	0.5	2.9	26.8
1,100	96.4	0.4	3.2	26.1

Distribution of noncondensible gaseous products varies widely because of the sensitivity of product distribution to carbonization operating parameters. Average noncondensible gas composition ranges are presented in Table 5. The heating value of the noncondensibles is approximately 11 MJ/m^3 (4, 16).

The condensible portion of wood pyrolysis products is divided into two fractions: water-soluble pyroligneous liquor and insoluble tars. Pyroligneous liquor is an 80% to 90% aqueous solution with major hydrocarbon components of acetic acid and methanol.

(15) Wood Chemistry, Volume 2, Second Edition. L. E. Wise and E. C. Jahn, eds. Reinhold Publishing Corporation, New York, New York, 1952. pp. 826-851.

(16) Riegel's Handbook of Industrial Chemistry, Seventh Edition. J. A. Kent, ed. Van Nostrand Reinhold Company, New York, New York, 1974. pp. 475-479.

TABLE 5. COMPOSITION RANGE FOR NONCONDENSIBLE PRODUCTS OF CHARCOAL MANUFACTURE (3, 16, 17)

Product	Percent of noncondensibles
Carbon dioxide	50 to 60
Carbon monoxide	22 to 33
Methane	3 to 18
Hydrogen	1 to 4
Higher hydrocarbons[a]	1 to 6

[a] "Higher hydrocarbons" are not defined by Reference 16, but are assumed to be nonmethane, noncondensible hydrocarbons.

Acetic acid is 4% to 7% of the condensible products (pyroligeneous liquor plus insoluble tars), methanol is 3% to 6%, and insoluble tars are 8% to 13% (3).

The insoluble tars can be further divided into three categories: light oils with boiling point below 200°C (aldehydes, ketones, acids, and esters); heavy oils boiling above 200°C (containing phenolic components); and pitch (16). Table 6 lists over 200 compounds that have been found in the liquid products from the destructive distillation of wood.

Technology

Batchwise Charcoal Production--

Charcoal was historically produced in pits or earthen kilns in which seasoned hardwood, about 1.2 m long and 150 mm to 200 mm in diameter, were piled in quantities of up to 90 cords. The wood was ignited, and covered by an earthen enclosure to limit but not prevent air leakage to the wood. Approximately 20 days were required to obtain yields of 20% (1).

Kilns of a variety of designs, capacities, and materials of construction are currently in operation, but the most common is the "Missouri-type" kiln shown in Figure 1 (13, 18). This type of kiln is constructed of concrete, typically processing 45 to 50 cords of wood per cycle. A typical cycle may be within the following time frame:

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(17) Hartwig, J. R. Control of Emissions from Batch-type Charcoal Kilns. Forest Products Journal, 21(9):49-50, 1971.

(18) Heflin, E. L., and R. Massengale. Missouri Charcoal Directory. Missouri Department of Conservation, Jefferson City, Missouri, April 1973. 10 pp.

TABLE 6. COMPOUNDS FORMED BY WOOD CARBONIZATION (15)

From WOOD CHEMISTRY, Second Edition, edited by L. E. Wise and E. C. Jahn
1952 Litton Educational Publishing, Inc.
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Formula	Name	Formula	Name	Formula	Name	Formula	Name
NH_3	Ammonia	$C_6H_{12}O$	Butyl methyl ketone	$C_5H_8O_2$	2-Pentenoic acid	$C_9H_{14}O$	Isophorone
CH_2O	Formaldehyde	$C_6H_{12}O$	3-Methyl-2-pentanone	$C_5H_8O_2$	4-Pentenoic acid	$C_9H_{14}O$	Amylfuran
CH_2O_2	Formic acid	$C_6H_{12}O_2$	Caproic acid	$C_5H_8O_2$	Tiglic acid	$C_9H_{16}O$	2,4,4-Trimethylcyclohexanone
CH_4O	Methanol	$C_6H_{12}O_2$	Isocaproic acid	$C_5H_8O_3$	δ-Hydroxyvalerolactone	$C_9H_{16}O$	Cyclohexanepropionaldehyde
CH_5N	Methylamine	$C_6H_{12}O_2$	α-Methylvaleric acid	$C_5H_8O_3$	γ-Hydroxyvalerolactone	$C_9H_{16}O$	3,3,5-Trimethylcyclopentanone
$C_2H_2O_2$	Glyoxal	$C_6H_{12}O_2$	Methyl valerate	$C_5H_8O_3$	Levulinic acid	$C_9H_{18}O_2$	Pelargonic acid
C_2H_4O	Acetaldehyde	C_7H_8	Toluene	$C_5H_8O_3$	Acetoxypropanone	$C_{10}H_8$	Naphthalene
$C_2H_4O_2$	Acetic acid	C_7H_8O	o-Cresol	$C_5H_8O_4$	β-Hydroxy-γ-hydroxyvalerolactone	$C_{10}H_{12}O$	Estragole
$C_2H_4O_2$	Methyl formate	C_7H_8O	m-Cresol	C_5H_{10}	Pentene	$C_{10}H_{12}O_2$	Eugenol
$C_2H_4O_2$	Glycolaldehyde	C_7H_8O	p-Cresol	$C_5H_{10}O$	3-Methyl-2-butanone	$C_{10}H_{12}O_2$	Isoeugenol
$C_2H_4O_3$	Glycolic acid	$C_7H_8O_2$	Guaiacol	$C_5H_{10}O$	Isovaleraldehyde	$C_{10}H_{14}$	Cymene
C_2H_6O	Ethyl alcohol	$C_7H_8O_3$	1-Methoxy-2,3-dihydroxybenzene	$C_5H_{10}O$	2-Pentanone	$C_{10}H_{14}$	Durene
C_2H_7N	Dimethylamine	$C_7H_8O_3$	5-Methyl pyrogallol	$C_5H_{10}O$	3-Pentanone	$C_{10}H_{14}O$	Thymol
$C_3H_4O_2$	Acrylic acid	C_7H_9N	Lutidine	$C_5H_{10}O$	Pivalaldehyde	$C_{10}H_{14}O_2$	4-Propylguaiacol
C_3H_6O	Acetone	$C_7H_{10}O$	1-Methyl-2-cyclohexen-5-one	$C_5H_{10}O$	Valeraldehyde	$C_{10}H_{14}O_3$	2,6-Dimethoxy-4-ethylphenol
C_3H_6O	Allyl alcohol	$C_7H_{10}O$	Propylfuran	$C_5H_{10}O_2$	α-Methylbutyric acid	$C_{10}H_{14}O_3$	A5-propyl-monomethyl ether of pyrogallol
C_3H_6O	Propionaldehyde	$C_7H_{10}O$	2,3,5-Trimethylfuran	$C_5H_{10}O_2$	Methyl butyrate	$C_{10}H_{16}$	Camphene
$C_3H_6O_2$	Methyl acetate	C_7H_{12}	1-Heptyne	$C_5H_{10}O_2$	1,2-Cyclopentanediol	$C_{10}H_{16}$	Limonene
$C_3H_6O_2$	Hydroxypropanone	$C_7H_{12}O$	Cyclohexanecarboxaldehyde	$C_5H_{10}O_2$	Methyl isobutyrate	$C_{10}H_{16}$	Nopinene
$C_3H_6O_2$	Propionic acid	$C_7H_{12}O$	Dimethylcyclopentanone	$C_5H_{10}O_2$	Isovaleric acid	$C_{10}H_{16}$	Pinene
C_3H_8O	Isopropyl alcohol	$C_7H_{12}O$	2-Ethyl-2,3-dihydro-5-methylfuran	$C_5H_{10}O_2$	4-Hydroxy-2-pentanone	$C_{10}H_{16}$	Sylvestrene
C_3H_8O	Propyl alcohol	$C_7H_{12}O_2$	5-Heptenoic acid	$C_5H_{10}O_2$	Valeric acid	$C_{10}H_{16}$	γ-Terpinene
$C_3H_8O_2$	Methylal	$C_7H_{14}O$	Butyrone	C_5H_{12}	Pentane	$C_{10}H_{16}$	Terpinolene
C_3H_9N	Trimethylamine	$C_7H_{14}O$	Enanthaldehyde	$C_5H_{12}O$	Isoamyl alcohol	$C_{10}H_{16}O$	Camphor
$C_4H_4O_3$	Succinic anhydride	$C_7H_{14}O_2$	Methyl caproate	$C_5H_{12}O_2$	Propionaldehyde dimethyl acetal	$C_{10}H_{18}O$	Borneol
C_4H_4O	Furan	$C_7H_{14}O_2$	Enanthic acid	C_6H_6	Benzene	$C_{10}H_{18}O$	Cineole
C_4H_6O	Crotonaldehyde	C_7H_{16}	Heptane	C_6H_6O	Phenol	$C_{10}H_{18}O$	Fenchyl alcohol
$C_4H_6O_2$	Biacetyl	C_8H_6O	Benzofuran	$C_6H_6O_2$	5-Methyl-2-furfuraldehyde	$C_{10}H_{18}O$	Isofenchyl alcohol
$C_4H_6O_2$	3-Butenoic acid	C_8H_{10}	m-Xylene	$C_6H_6O_2$	2-Furyl methyl ketone	$C_{10}H_{18}O$	α-Terpineol
$C_4H_6O_2$	Butyrolactone	$C_8H_{10}O$	o-Ethylphenol	$C_6H_6O_2$	Catechol	$C_{10}H_{20}O_2$	Capric acid
$C_4H_6O_2$	Crotonic acid	$C_8H_{10}O$	2,3-Xylenol	$C_6H_6O_3$	5-(Hydroxymethyl)-2-furfuraldehyde	$C_{11}H_{16}O$	1,3,3-Trimethylbicyclo[2.2.2]-5-octen-2-one
$C_4H_6O_2$	Methacrylic acid	$C_8H_{10}O$	2,4-Xylenol	$C_6H_6O_3$	4-Methyl-2-furoic acid	$C_{11}H_{16}O_3$	5-Propyl-1,3-dimethoxy-2-hydroxybenzene
$(C_4H_6O_2)_n$	Methacrylic acid, polymer	$C_8H_{10}O$	3,5-Xylenol	$C_6H_6O_3$	Methyl 2-furoate	$C_{15}H_{12}O_3$	2,5-Difurfurylidene-1-cyclopentanone
C_4H_8O	2-Butanone	$C_8H_{10}O_2$	Creosol	$C_6H_6O_3$	Maltol	$C_{15}H_{24}$	Cadinene
C_4H_8O	2-Buten-1-ol	$C_8H_{10}O_2$	6-Methylguaiacol	$C_6H_6O_3$	Pyrocinchonic anhydride	$C_{15}H_{32}$	Pentadecane
$C_4H_8O_2$	Butyric acid	$C_8H_{10}O_3$	2,6-Dimethoxyphenol	$C_6H_6O_3$	Pyrogallol	$C_{16}H_{32}O_2$	Palmitic acid
$C_4H_8O_2$	Isobutyric acid	$C_8H_{10}O_3$	Methoxy-4-homocatechol	C_6H_7N	2-Picoline	$C_{17}H_{36}$	Heptadecane
$C_4H_8O_2$	Methyl propionate	$C_8H_{12}O$	2,4-Dimethyl-4-cyclohexene-1-one	C_6H_8O	2-Methyl-2-cyclopenten-1-one	$C_{18}H_{12}$	Chrysene
$C_4H_{10}O$	Isobutyl alcohol	$C_8H_{12}O$	Methylcyclopentanone	C_6H_8O	4-Methyl-2-cyclopenten-1-one	$C_{18}H_{18}$	Retene
$C_4H_{10}O_2$	Acetaldehyde dimethyl acetal	$C_8H_{12}O$	3-Isopropyl-2-cyclopenten-1-one	C_6H_8O	2,5-Dimethylfuran	$C_{18}H_{34}O_2$	Oleic acid
$C_4H_{10}O_2$	1,2-Dimethoxyethane	$C_8H_{14}O$	Trimethylcyclopentanone	$C_6H_8O_2$	1-(3 or 4)-Cyclohexanedione	$C_{18}H_{36}O_2$	Stearic acid
$C_5H_4O_2$	2-Furfuraldehyde	$C_8H_{14}O_2$	3,6-Octanedione	$C_6H_8O_2$	2-Hydroxy-3-methyl-2-cyclopenten-1-one	$C_{18}H_{38}$	Octadecane
$C_5H_4O_3$	2-Furoic acid	$C_8H_{16}O_2$	Caprylic acid	$C_6H_{10}O$	α-Methyl-β-ethylacrolein	$C_{19}H_{40}$	Nonadecane
C_5H_5N	Pyridine	$C_8H_{16}O_2$	Methyl enanthate	$C_6H_{10}O$	Cyclohexanone	$C_{20}H_{30}O_2$	Abietic acid
C_5H_6O	2-Cyclopenten-1-one	$C_8H_{16}O_4$	Dihydroxycaprylic acid	$C_6H_{10}O$	3-Hexen-2-one	$C_{20}H_{30}O_2$	Pimaric acid
C_5H_6O	2-Methylfuran	$C_9H_{10}O_2$	4-Vinylguaiacol	$C_6H_{10}O$	Mesityl oxide	$C_{20}H_{40}O_2$	Arachidic acid
C_5H_6O	3-Methylfuran	C_9H_{12}	Cumene	$C_6H_{10}O_3$	1-Hydroxy-2-butanone acetate	$C_{20}H_{42}$	Eicosane
$C_5H_6O_2$	Furfuryl alcohol	C_9H_{12}	Pseudocumene	$C_6H_{10}O_2$	2,3-Hexanedione	$C_{21}H_{44}$	Heneicosane
C_5H_8O	Cyclopentanone	$C_9H_{12}O_2$	3,4-Dimethylguaiacol	$C_6H_{10}O_2$	4-Methyl-2-pentenoic acid	$C_{22}H_{44}O_2$	Behenic acid
C_5H_8O	Tiglaldehyde	$C_9H_{12}O_2$	4-Ethylguaiacol	$C_6H_{10}O_3$	Hydroxy-2-propanone propionate	$C_{22}H_{46}$	Docosane
$C_5H_8O_2$	Angelic acid	$C_9H_{12}O_2$	Homoveratrole	$C_6H_{10}O_5$	Levoglucosan	$C_{23}H_{48}$	Tricosane
$C_5H_8O_2$	Methyl crotonate	$C_9H_{12}O_3$	2,6-Dimethoxy-4-methylphenol	$C_6H_{12}O$	Cyclohexanol	$C_{24}H_{48}O_2$	Lignoceric acid
$C_5H_8O_2$	2,3-Pentanedione	$C_9H_{12}O_3$	5-Propylpyrogallol	$C_6H_{12}O$	Tetrahydro-2,5-dimethylfuran	$C_{30}H_{60}$	Melene
				$C_6H_{12}O$	3-Hexanone		

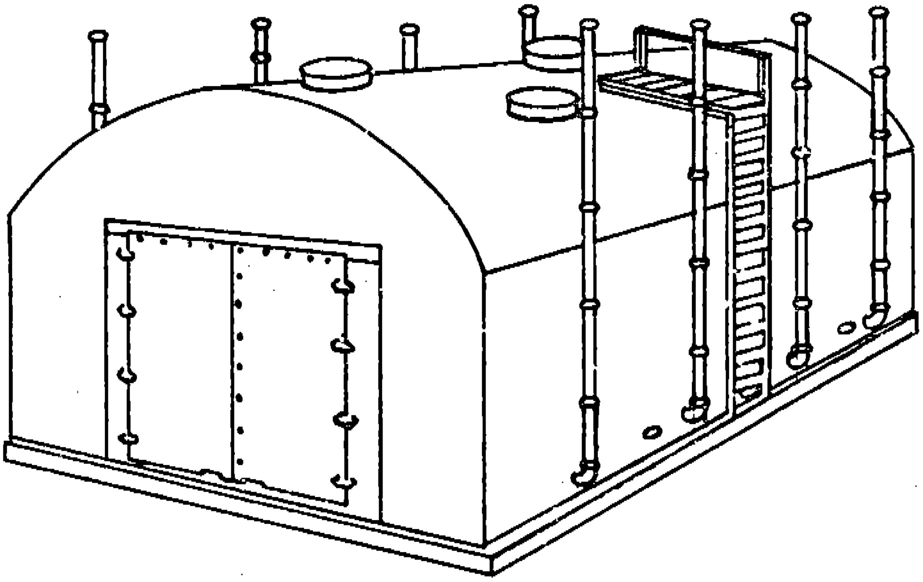

Figure 1. "Missouri-type" charcoal kiln (13).

1 to 2 days	load
5 to 8 days	pyrolysis
10 to 14 days	cool
1 to 2 days	unload (19)

After the wood is manually loaded in the kiln, a fire is started, usually at the bottom center of the kiln, by igniting easily combustible materials placed at this point during the loading. During ignition, a large amount of air is necessary for the rapid combustion of the starting fuels to insure the heat level needed for pyrolysis. This air is supplied through groundline ports in the kiln side walls or through temporary openings under the kiln door. In some cases, the kiln doors remain open until the burn is adequately started.

Auxiliary ceiling ports in some kilns serve as temporary stacks and aid ignition by causing greater amounts of air to be drawn into the kiln through the air ports. They also aid removal of smoke from the kiln.

Ignition patterns are generally similar for all types of kilns. During the first 5 min to 15 min, temperatures in the ignition

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(19) Maxwell, W. H. Stationary Source Testing of a Missouri-Type Charcoal Kiln. Contract No. 68-02-1403 (PB 258 695), Environmental Protection Agency, Kansas City, Missouri, August 1976. 178 pp.

area will rise rapidly to about 540°C. After much of the fuel has been burned, the temperatures will quickly drop, often to as low as 150°C. The extent of the temperature drop is closely related to conditions of air supply and to the moisture content of the charge. With the establishment of a suitable ignition zone, however, the temperature gradually increases to about 280°C, and the ignition period is considered complete.

Satisfactory carbonization depends primarily on maintenance of proper burning conditions in the pyrolysis zone. Sufficient heat must be generated first to dry the wood and then to maintain temperatures necessary for efficient carbonization. At the same time, the burning must be limited so that only sufficient heat is present to produce good charcoal. Temperature control is attained by varying the size of the air port openings providing air for combustion of wood volatiles.

For the production of good-quality charcoal, kiln temperatures from about 450°C to 510°C are required. Prolonged higher temperatures will reduce the yield of charcoal without necessarily upgrading it for recreational use. If, on the other hand, pyrolysis temperatures remain low, the charcoal may be too "smoky" for domestic use, and larger than normal amounts of brands (partially charred wood) will be produced.

The direction and rate of spread of the pyrolysis zone is associated with a number of factors, such as location of air ports and stacks, volume and velocity of the incoming air, wood size and moisture content, piling of the charge, and design of the kiln. Pyrolysis generally proceeds at a faster rate at the upper part of the charge, where higher temperatures are available for longer periods of time. Less rapid pyrolysis takes place near the kiln floor, where the average temperature usually is lowest. In the "Missouri-type" kiln, combustion and carbonization progresses from the top of the kiln to the floor and from the center to the walls.

Burn progress can be determined by the color of the smoke from the kiln or by determining the temperature along the vertical distance of the steel doors. The pyrolysis is completed when fire has reached the floor of the kiln as determined by view ports (air intake ports) at the floor level. This may also be indicated by a marked decrease in the volume of smoke and a color change from grayish yellow to bluish white.

When pyrolysis has been completed, all air ports are sealed for the start of the cooling cycle. After the ports are sealed, the stacks remain open until smoking has practically stopped to prevent the development of gas pressure in the kiln. Stacks can usually be sealed from 1 hr to 2 hr after the air ports are closed. The kiln is allowed to cool for about 10 days to 14 days before removing the charcoal. Yields of approximately 25% are achieved.

"Missouri-type" kilns typically have eight exhaust stacks approximately 4.6 m high along the side walls of the kiln. Other types of kilns have various numbers of exhausts. Pyrolysis time and emissions vary with the kiln type and kiln capacity and among different operators of the "Missouri-type" kiln, and are also dependent on wood type and moisture content (1, 13).

Continuous Charcoal Production--
An increasing percentage of charcoal is produced continuously with the application of multiple hearth furnaces to charcoal manufacture. Advantages of multiple hearth furnaces include:

- Lower labor requirements than kiln operations where manual loading and unloading is needed. Only one man per shift is required for continuous facilities.
- Consistent yield and quality charcoal with easy control of product volatile and fixed carbon content.
- Feed of multiple forms of wood waste.
- Operation by "art" reduced to a minimum.
- Off-gases easily collected for further processing (20).

An example of this type of facility is the Herreshoff multiple hearth furnace (21) consisting of several hearths or burning chambers stacked one on top of the other (Figure 2). The number of hearths employed depends upon the process and the heat load. The hearths are contained in a cylindrical, steel, refractory-lined shell and are divided by refractory decks which function as the floor of one hearth and the roof of the hearth below.

Passing up through the center of the furnace is a shaft to which are attached two to four rabble arms for each hearth. As the shaft turns (usually 1 rpm to 2 rpm), the hogged material resting on the hearth floors is continually agitated, exposing fresh material to the hot gases being evolved. A further function of the rabble arms is to move material through the furnace. On alternate hearths, the teeth are canted to spiral the material from the shaft toward the outside wall of the furnace or from the outside wall toward the center shaft. Around the center shaft is an annular space through which material drops on alternate hearths, while on the remaining hearths material drops through

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(20) Gallagher, F. Use of the Multiple Hearth Furnace in the Production of Charcoal from Wood Waste. In: Third Texas Industrial Wood Seminar, Wood Residue Utilization, Texas Forest Products Laboratory, Lufkin, Texas, 1969. pp. 13-20.

(21) Wastewater Engineering, Collection, Treatment Disposal. B. J. Clark and M. A. Ungersma, eds. McGraw-Hill Book Co., New York, New York, 1972. pp. 320.

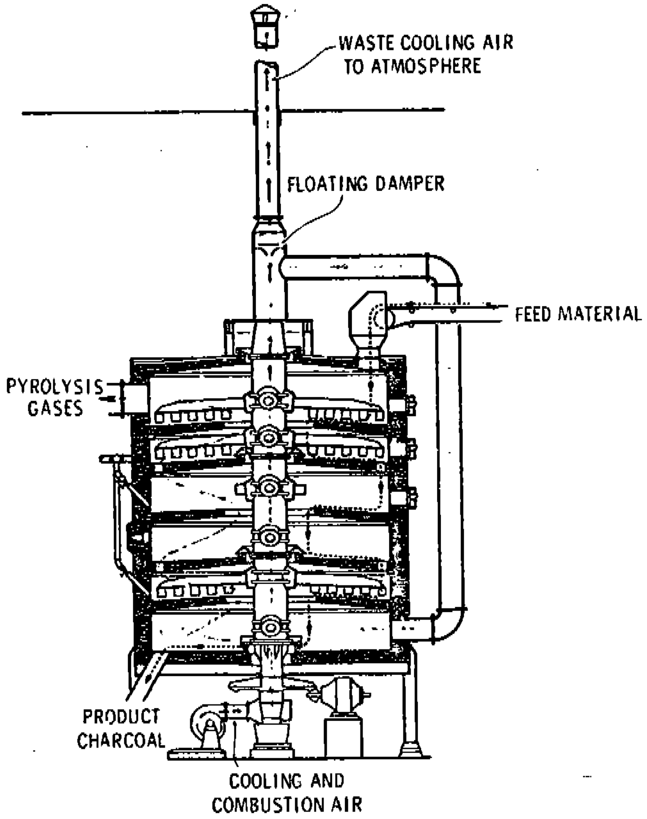

Figure 2. Herreshoff multiple hearth furnace (21).

From Wastewater Engineering: Collection, Treatment, Disposal
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holes in the outer periphery of the hearth floor. In this way, material fed at the top of the furnace moves alternately across the hearths at increasing temperatures until it discharges from the floor of the bottom hearth.

Initial heat for startup is provided by oil- or gas-fired burners mounted in the sides of the hearths. When furnace temperature has been attained, the auxiliary fuel ceases, and combustion air is used to ignite the evolving wood gases to maintain furnace temperature. Combustion gases exit from the top hearth either to stacks approximately 21 m in height (5, 22) or to ductwork for transport to a boiler or air pollution control equipment. Furnace temperatures range between 480°C and 650°C.

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(22) Anderson, E. A. New Ways in Wood Products. Forest Products Journal, 23(9):56-58, 1973.

Charcoal exiting from the furnace is cooled by water sprays and water jacketing on a cooler. These sprays are controlled automatically by a temperature regulator set for a given charcoal temperature.

While the furnace can operate with any wood or wood waste or combination of wastes, it is important that the material fed does not have too great a size range so that carbonization will be even throughout. Capacity for this type of unit averages 2.5 metric tons/hr of charcoal with a conversion efficiency of approximately 25% (23).

For comparison, a 50-cord batch kiln produces approximately 16 metric tons of charcoal over about a 3-wk cycle.

Lignite can be carbonized for charcoal manufacture in Lurgi carbonizers of conventional design. Crushed lignite is fed into a drying section, which is the topmost of three vertically superimposed sections of the carbonizer shaft. Drying gas circulates through the drying section, countercurrent to the slowly downward moving lignite. Standpipes at the bottom discharge the dried material into the middle carbonizing section. The drying gas maintains the drying section at about 260°C. The carbonizing section is where a portion of the volatile matter is driven off. It operates at about 590°C. These gases and volatile products are fed to a byproduct treatment auxiliary system. Some byproduct gas from the carbonization is burned in a combustor; the hot combustion products are used to heat the carbonizing section. The carbonized lignite is discharged into the cooling section where the product is cooled by circulating cool gas and then discharged to storage (24).

Charcoal Briquetting--
Fabrication of briquets from raw charcoal may be an integral part of a charcoal-producing facility, or the operation may be independent with charcoal being purchased as raw material. Figure 3 presents a flow diagram for briquet production.

Charcoal is first hammermilled or crushed to pass a 3.175 mm screen aperture and stored for briquetting. The charcoal is mixed with a 9% to 10% (by weight) solution of binder (corn-, milo-, or wheatstarch, or other) to form a 65% to 70% charcoal mixture. Other materials such as sawdust may also be added to effect faster burning or higher temperature (24). Briquets are

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(23) Koch, P. Utilization of the Southern Pines, Volume II. Agricultural Handbook No. 420, U.S. Department of Agriculture, Pineville, Louisiana, 1972. pp. 1499-1504.

(24) Giammar, R. D., R. B. Engdahl, and P. E. Barrett. Emissions from Residential and Small Commercial Stoker-Coal-Fired Boilers under Smokeless Operation. EPA 600/7-76-029, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1976. pp. 63-64.

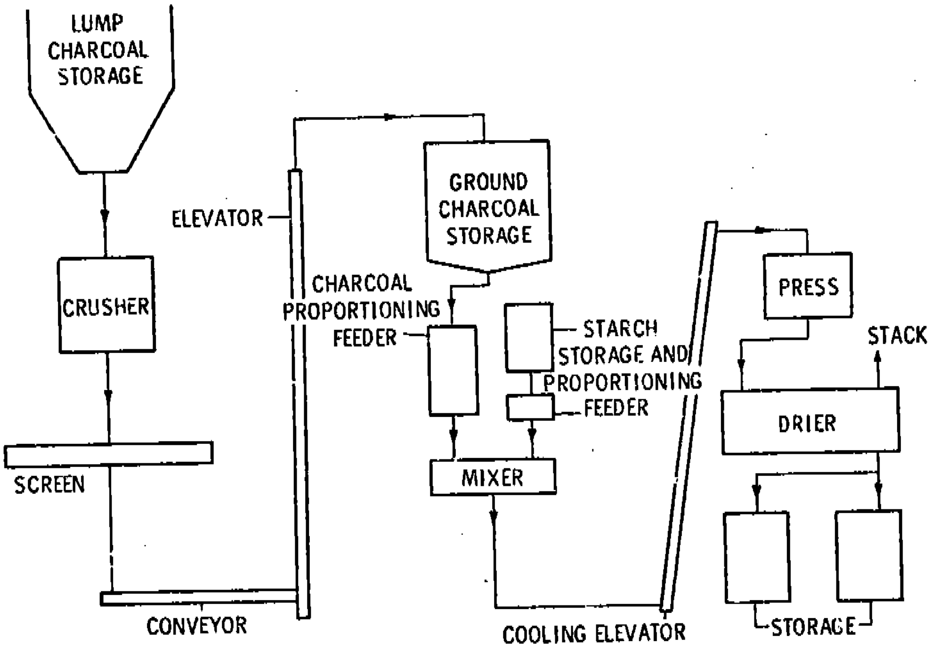

Figure 3. Charcoal briquetting flow diagram (1).

then formed in a press and dried for 3 hr to 4 hr at approximately 135°C to obtain a product having a 5% moisture content. This composition results in a briquet of approximately 90% pyrolysis product. A 90% charcoal briquet was assumed for this report. Industrial contacts suggested that the carbonized material content of a charcoal briquet may be lower (personal communication, A. W. Seeds, Charcoal Briquet Institute, 6 September 1977). Production equipment ranges in capacity from 0.9 to 9 metric tons per hour (1, 23). The dryer is assumed to have a 7.6-m stack.

INDUSTRY STATUS

A current, complete, and accurate characterization of the charcoal manufacturing industry is not available. The most recent thorough investigation of the industry was conducted by the U.S. Department of Agriculture Forest Service Division of Forest Economics and Marketing Research in 1961 (8). Compilation of current information sources revealed inadequacies. To update and elaborate on the available data, an industry survey was attempted, with limited success due to lack of industry response. The following is the best currently available, traceable characterization of the charcoal manufacturing industry.

Source Population

The best available source population data are presented in Appendix A, which lists producer, location, and production or capacity. Not all sources have production data, but those having information account for approximately 420,000 metric tons annual production. The accuracy of these population data is questionable when compared with a 1972 charcoal industry analysis which lists the four largest U.S. charcoal producers and their 1972 estimated market shares: Kingsford Co. (37%), a subsidiary of Husky Oil Canada, Ltd. (15%), Great Lakes Carbon (7%), and a joint venture of Georgia-Pacific and Cook Industries (7%) (25). Combined, these four producers manufacture approximately 66% of U.S. charcoal, but in Appendix A, they represent only approximately 23% of the identified production.

Estimates of 1975 charcoal production range from 132,000 metric tons to 825,000 metric tons, with 590,000 metric tons being most representative (personal communication, A. W. Seeds, Charcoal Briquet Institute, 27 February 1976) (9, 20, 25-29). Although the references are not on a consistent basis and report either briquet sales, charcoal sales, briquet production, charcoal production, briquet consumption, or charcoal capacity, 590,000 metric tons charcoal briquet production is considered a conservative figure for this study. Assuming 90% of charcoal is briquetted and 90% of each briquet is charcoal, then approximately 590,000 metric tons of raw charcoal were produced. Of this 590,000 metric tons, an estimated 55% is produced in continuous multiple-hearth furnace facilities, while the remaining estimated 45% is produced in batch kilns (personal communication, A. W. Seeds, Charcoal Briquet Institute, 27 February 1976).

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(25) Kingsford Company. The Wall Street Transcript, 37(5):29394-29395, 1972.

(26) Hopper, T. G., and W. A. Marrone. Impact of New Source Performance Standards on 1985 National Emissions from Stationary Sources, Volume I. Contract 68-02-1382, Task 3, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1975. p. 54.

(27) Rolke, R. W., R. D. Hawthorne, C. R. Garbett, E. R. Slater, T. T. Phillips, and G. D. Towell. Afterburner Systems Study. EPA-R2-72-062 (PB 212 560), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1972. pp. 289-306.

(28) Blyth, J. E., and R. Massengale. Missouri's Primary Forest Products Output and Industries, 1969. PB 226 468, U.S. Department of Agriculture, St. Paul, Minnesota, October 1973. p. 7.

(29) Floyd, J. R. Screening Study Summary Report - Raw Charcoal Manufacture. U.S. Environmental Protection Agency, Research Triangle Park, January 1976. 4 pp.

Based on the representative source definition given in Section 4, there is an estimated 1975 population of 1,330 batch kilns. Although the number of kilns has been estimated to be lower, 750 kilns to 1,000 kilns (personal communication, A. W. Seeds, Charcoal Briquet Institute, 31 August 1977), further calculations requiring the number of batch kilns use the 1975 estimate of 1,330 kilns. There were also an estimated 16 continuous multiple-hearth furnaces and 32 charcoal briquetting plants in the United States (personal communication, A. W. Seeds, Charcoal Briquet Institute, 31 August 1977).

Current data are not available in the literature or from industry concerning raw material breakdown, percentage of raw charcoal briquetted, percentage of briquets made from captive raw charcoal sources, or the number of charcoal plants. The following is conjecture on these topics based on information compiled in 1961 and trends in the industry. In 1961, 92% of the charcoal produced was derived from medium to dense hardwoods such as beech, birch, hard maple, hickory, and oaks. With the application of carbonization to the reduction of waste materials (e.g., fruit pits and nut shells), the percentage has probably declined, but the great majority of charcoal probably is still produced from hardwoods. The percentage of raw charcoal that is converted to briquets has been growing as charcoal has become more and more a recreational fuel. In 1961, 69% of the charcoal produced was briquetted, while the current figure is probably near the upper end of the 80% to 90% range. Discussions of the number of charcoal plants and percentage of captive charcoal used for briquet production are closely related. As stated above, the number of production units has declined to 1,330 in 1975 from 1,977 units in 1961. It is likely that the number of plants has declined by the same percentage from 297 plants in 1961. In 1975 there were only 32 briquetting plants, while in 1961 there were 50. The approximate decline of 35% in the number of processing units, charcoal plants, and briquetting plants since 1961, along with the near doubling of production (298,000 metric tons in 1961 versus an estimated 590,000 metric tons in 1975) suggest a trend toward larger facilities. Larger facilities probably would devote more attention to securing sources of raw materials and would therefore probably result in larger captive raw charcoal production (61% in 1961) (8).

Geographical Distribution

As with the general population data, information on the regional distribution of the charcoal manufacturing industry is limited. The industry is located primarily in the southeast quadrant of the United States. Missouri is the largest charcoal-producing state (54% of plants and 45% of available production data listed in Appendix A) (18, 28). Table 7 lists the number of producers and identified production by state as listed in Appendix A.

TABLE 7. GEOGRAPHICAL DISTRIBUTION OF CHARCOAL MANUFACTURERS

State	Number of producers	Identified production, metric tons
Alabama	3	-[a]
Arkansas	16	40,000
California	3	23,000
Florida	1	-[a]
Georgia	1	-[a]
Kansas	1	-[a]
Kentucky	1	-[a]
Illinois	1	-[a]
Maryland	2	5,000
Minnesota	1	7,400
Mississippi	4	15,300
Missouri	85	190,000
New Jersey	1	-[a]
North Dakota	1	30,000
Ohio	4	49,000
Oklahoma	5	8,000
Oregon	2	-[a]
Pennsylvania	1	-[a]
South Carolina	1	9,720
Tennessee	8	10,700
Texas	5	-[a]
Virginia	1	28,200
West Virginia	6	-[a]
Wisconsin	1	4,100
TOTAL	155	420,000[b]

[a] State production has not been reported.

[b] Does not add due to rounding. Total implies that 170,000 metric tons of production have not been reported.

SECTION 4

EMISSIONS

CHARACTERIZATION OF EMISSIONS

The manufacture of charcoal without emission control can result in the emission of any of the products of pyrolysis of carbonaceous materials. Over 200 products of wood pyrolysis have been identified (see Table 6), and the list is not complete. Information on emissions from the charcoal manufacturing industry was obtained from the literature (3, 16, 17, 19, 27, 30-34), as essentially the only available source of such data. Literature sources quantified uncontrolled emissions, either by estimate or by sampling, for uncontrolled emissions of: particulate, carbon monoxide, methanol, acetic acid, methane, polycyclic organic matter, and other gases. These species are found in the uncontrolled emissions of both batch and continuous charcoal manufacture. Similarly, particulate emissions from briquetting operations have also been estimated in the literature.

Very few data are available to characterize emissions from charcoal manufacture. Most estimates found in the literature derive

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(30) Compilation of Air Pollutant Emission Factors, Second Edition. AP42, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1972. p. 5.4.1.

(31) Keeling, B. F. Emission Testing the Missouri Type Charcoal Kiln. Preprint of Paper 76-37.1 presented at the 69th Annual Meeting of the Air Pollution Control Association, Portland, Oregon, 1976. 6 pp.

(32) National Emission Data System Point Source Listing - Charcoal Manufacture. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 19 June 1975. 113 pp.

(33) Fernandez, J. H. Why Not Burn Wood? Chemical Engineering, 84(11):159-16 , 1977.

(34) Control Techniques for Nitrogen Oxide Emissions from Stationary Sources. U.S. Department of Health, Education, and Welfare. Washington, D.C. NAPCA Publication No. AP-67 (PB 190 265), March 1970. 115 pp.

from material-balance calculations based on laboratory wood pyrolysis studies. When reported even field-sampling data from "Missouri-type" kilns are of questionable utility due to the improvisational sampling techniques utilized. The necessary modifications of the sampling technique cast doubt on the representative nature of the resulting data.

Uncontrolled emissions estimates, derived from the literature, presented in Table 8 do not distinguish between batch and continuous charcoal production (personal communication, multiple industrial sources, and 13, 16, 17, 19, 27, 30-34). Although overall annual emissions might possibly be independent of production technique, the cyclic (batch) versus continuous emission rate and composition would be an important consideration in the development of emission control. The "worst case" situation for the industry would be to consider that no emissions control is applied. It is, however, known that control technology is applied, even though the extent and efficiency of application are undocumented. Estimated controlled emission factors are presented in Table 8 based on the following assumptions: efficiency of batch kiln afterburners of 85% (13, 17), efficiency of continuous furnace afterburners of 95% (personal communication, B. L. Winter, Clorox Company, 26 August 1977), and efficiency of particulate emission control for briquetting operation of 95%. The accuracy of the emission estimates is uncertain at best.

TABLE 8. RANGE OF EMISSION FACTORS FOR CHARCOAL MANUFACTURE (3, 16, 17, 19, 27, 30-34) (g/kg charcoal)

	Emission factor				
	Uncontrolled		Controlled[a]		
Emission species	Charcoal manufacture	Briquetting	Batch kiln	Continuous furnace	Briquetting
Particulate[b]	28 to 406	7 to 42	2.1 to 61	0.7 to 20	0.35 to 2.1
Carbon monoxide	160 to 179	-[c]	24 to 27	8.0 to 8.9	-[c]
Methanol	67 to 76	-[c]	10 to 11	3.3 to 3.8	-[c]
Acetic acid	102 to 116	-[c]	15 to 17	5.1 to 5.8	-[c]
Other gases[d]	7 to 60	-[c]	1.0 to 9.0	0.4 to 3.0	-[c]
Methane	44 to 57	-[c]	6.6 to 8.6	2.2 to 2.9	-[c]
Hydrogen	0.5 to 2.0	-[c]	0.08 to 0.3	0.03 to 0.1	-[c]
Nitrogen oxides[e]	12	-[c]	13	13	-[c]
Polycyclic organic materials	0.004	-[c]	0.0006	0.0002	-[c]

[a] Controlled emission factors are estimates based on the following control efficiency assumptions: batch kiln afterburners, 85%; continuous furnace afterburners, 95%; briquetting emission control, 95%.

[b] Includes tar, oil, and pyroacids.

[c] No information.

[d] Includes compounds identified in the literature as "higher hydrocarbons" (assumed to be nonmethane noncondensibles), ethane, formaldehyde, and unsaturated hydrocarbons (e.g., ethylene).

[e] Uncontrolled emission factor is based on the assumption that all wood nitrogen, 0.14% (33), is oxidized and no thermal fixation of air nitrogen (34). Controlled emission factor adds 3.23×10^{-2} g/MJ (27) due to thermal fixation of air in afterburning.

POTENTIAL ENVIRONMENTAL EFFECTS

There are several approaches to estimating the environmental impact of air emissions from an industry. Each approach yields a comparative value. These values are designed to answer the following questions: Do the emissions represent a potential hazard to population? Do the quantities of emissions from the industry represent a significant fraction of the total national emissions from all sources? Do the quantities of emissions from the industry in a state where it operates represent a significant fraction of emissions from all sources in that state? If emissions represent a hazard potential, how large a population might be affected? At what rate is the industry estimated to grow (decline)? Considered in aggregate, the answers to these questions reasonably describe the potential environmental impact of industry emissions. Each of these evaluation criteria is discussed in turn below.

In deriving the numerical answers to the above questions, it is desirable to operate with a representative (typical or average) production unit. This representative unit, or plant, is defined as one with operating parameters and other quantitative characteristics that are the average values for all plants within the industry. Thus, in order to evaluate the environmental effects of charcoal production, it is necessary to define a representative (typical or average) charcoal production unit. Because of the distribution of charcoal production between batch units and continuous units, representative source definitions are required for each type as well as for briquetting facilities.

A representative batch kiln as defined in Reference 13 is a 50-cord "Missouri-type" facility producing 200 metric tons/yr (16 metric tons/cycle) of charcoal with a capacity of 280 metric tons/yr. It produces airborne emissions from its open doors during startup and from its eight uncontrolled exhaust stacks, each 4.6 m high for the remainder of the cycle. A typical plant has 12 kilns. The operation of this type of unit is described in Section 3 (13).

Continuous furnaces for charcoal production are of varied sizes. A representative continuous furnace is defined as a Herreshoff-type, multiple-hearth furnace with an average production rate. It produces 2.5 metric tons/hr of charcoal for an estimated 8,000 hr/yr, yielding an annual production rate of 20,000 metric tons/yr of charcoal (personal communication, A. W. Seeds, Charcoal Briquet Institute, 31 August 1977). It has only one emission source, the stack, which is approximately 21 m high. The operation of this type of unit is described in Section 3 (5, 20, 22). Both batch and continuous units are assumed to be fed with hardwoods. The batch unit uses roundwood, while the continuous facility uses hogged wood.

Definition of a representative briquetting facility assumes that each facility has only one drying oven, the major potential emission source. Thirty-two briquetting facilities annually producing 590,000 metric tons of briquets yield an average facility processing approximately 18,000 metric tons/yr of briquets (personal communication, A. W. Seeds, Charcoal Briquet Institute, 27 February 1976). Individual briquetting units produce 0.9 to 9 metric tons/hr of briquets. An emission height of 7.6 m is assumed. Briquetting is described in Section 3.

To evaluate the potential hazard of the emissions, the actual (or estimated) concentration of each pollutant species in the vicinity of the plant is compared with the concentration of the species considered safe for prolonged exposure. If the numerical value of this ratio is greater than 1.0, a hazard is considered to exist. If the value is between 0.1 and 1.0, a hazard might exist.

In practice, the ground level concentration of emission species downwind from the representative source is compared to the ambient air quality standard for the criteria pollutants,[a] or to a reduced threshold limit value (TLV) for noncriteria emission species. This comparison is defined as the source severity, S, and given by:

$$S = \frac{\overline{X}_{max}}{F} \tag{2}$$

where $\overline{X}_{max}$ = average maximum ground level concentration for each emission species

F = primary ambient air quality standard for criteria pollutants (particulates, sulfur oxides, nitrogen oxides, and hydrocarbons)

or

$$F = \text{TLV} \times \frac{8}{24} \times \frac{1}{100}, \text{ for noncriteria emission species,}$$

and

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[a] Criteria pollutants are those for which air quality standards have been established or guidelines have been proposed. They include carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrocarbons, and particulate.

TLV = threshold limit value for each species

$\frac{8}{24}$ = correction factor to adjust the TLV to a 24-hr exposure level

$\frac{1}{100}$ = safety factor

The value of $\overline{\chi}_{max}$ for a representative source is defined as (35)

$$\overline{\chi}_{max} = \chi_{max}\left(\frac{t_o}{t}\right)^{0.17} \tag{3}$$

where $\chi_{max} = \frac{2\,Q}{\pi e \bar{u} h^2}$ (4)

and
Q = emission rate, g/s
π = 3.14
e = 2.72
$\bar{u}$ = average wind speed, 4.5 m/s (national average)
h = stack height, m
t_o = short-term averaging time, 3 min
t = averaging time, min

The equation for χ_{max} (Equation 4) is derived from the general plume dispersion equation for an elevated point source, ground level ($z = 0$) concentration, radially ($y = 0$) downwind from the source, and for U.S. average atmospheric stability conditions (35).

A detailed derivation of severity equations is presented in Appendix B. It was assumed that the stack height, h, was equal to the emission height, H; i.e., that the plume rise was negligible. Table 9 presents the ranges of S for each emission species for both controlled and uncontrolled representative sources. Sample calculations are presented in Appendix C.

The potential environmental impact of emissions from charcoal manufacture can also be evaluated by comparing the nationwide mass of each criteria emission from charcoal production to the total nationwide mass of each criteria emission from all sources. Actual national charcoal manufacture emissions cannot be calculated because of a lack of information regarding the application and efficiency of control technology. However, estimated nationwide emissions were calculated using the efficiencies of control

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(35) Turner, D. B. Workbook of Atmospheric Dispersion Estimates, 1970 Revision. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

TABLE 9. RANGE OF TIME-AVERAGED MAXIMUM GROUND LEVEL CONCENTRATIONS AND SOURCE SEVERITIES FOR CHARCOAL MANUFACTURE

Emission species	TLV, g/m^3	Batch kiln		Continuous furnace		Briquetting	
		Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled
		Time-averaged maximum ground level concentration ($\bar{\chi}_{max}$, g/m^3)[a]					
Particulate[b]	2.6×10^{-4}[c]	6.7×10^{-5} to 9.8×10^{-4}	4.5×10^{-4} to 6.5×10^{-3}	3.9×10^{-5} to 5.7×10^{-4}	7.9×10^{-4} to 1.1×10^{-2}	7.0×10^{-5} to 4.2×10^{-4}	1.4×10^{-3} to 8.4×10^{-3}
Carbon monoxide	4.0×10^{-2}	6.6×10^{-4} to 7.4×10^{-4}	4.4×10^{-3} to 4.9×10^{-3}	3.9×10^{-4} to 4.3×10^{-4}	7.7×10^{-3} to 8.6×10^{-3}	—[d]	—[d]
Methanol	2.6×10^{-1}	1.6×10^{-4} to 1.8×10^{-4}	1.1×10^{-3} to 1.2×10^{-3}	9.4×10^{-5} to 1.1×10^{-4}	1.9×10^{-3} to 2.1×10^{-3}	—[d]	—[d]
Acetic acid	2.5×10^{-2}	2.5×10^{-4} to 2.8×10^{-4}	1.7×10^{-3} to 1.9×10^{-3}	1.4×10^{-4} to 1.6×10^{-4}	2.9×10^{-3} to 3.3×10^{-3}	—[d]	—[d]
Other gases[e]	1.6×10^{-4}[f]	3.4×10^{-5} to 2.1×10^{-4}	1.6×10^{-4} to 1.4×10^{-3}	1.4×10^{-5} to 1.2×10^{-4}	2.8×10^{-4} to 2.4×10^{-3}	—[d]	—[d]
Methane	—[g]	—[g]	—[g]	—[g]	—[g]	—[d]	—[d]
Hydrogen	—[g]	—[g]	—[g]	—[g]	—[g]	—[d]	—[d]
Nitrogen oxides	1.0×10^{-4}[c]	3.0×10^{-4}	2.8×10^{-4}	4.6×10^{-4}	4.2×10^{-4}	—[d]	—[d]
Polycyclic organic materials	1.0×10^{-6}[h]	9.6×10^{-9}	6.5×10^{-8}	5.7×10^{-9}	1.1×10^{-7}	—[d]	—[d]
		Source severity, S					
Particulate[b]		0.26 to 3.7	1.7 to 25	0.15 to 2.2	3.0 to 44	0.27 to 1.6	5.4 to 32
Carbon monoxide		0.016 to 0.018	0.11 to 0.12	0.0097 to 0.011	0.19 to 0.22	—[d]	—[d]
Methanol		0.19 to 0.21	1.2 to 1.4	0.11 to 0.12	2.2 to 2.5	—[d]	—[d]
Acetic acid		3.0 to 3.4	20 to 23	1.7 to 2.0	35 to 39	—[d]	—[d]
Other gases[e]		0.2 to 1.3	1.0 to 8.5	0.09 to 0.8	1.7 to 15	—[d]	—[d]
Methane		—[g]	—[g]	—[g]	—[g]	—[d]	—[d]
Hydrogen		—[g]	—[g]	—[g]	—[g]	—[d]	—[d]
Nitrogen oxides		3.0	2.8	4.6	4.2	—[d]	—[d]
Polycyclic organic materials		2.9	19	1.7	34	—[d]	—[d]

[a] Emissions assumed constant over period of emission, batch 2,971 hr/yr, continuous and briquetting 8,000 hr/yr. Also assumed one emission per source.

[b] Includes tar, oil, and pyroacids.

[c] Primary ambient air quality standard.

[d] No information.

[e] Includes compounds, identified in the literature as "higher hydrocarbons" (assumed to be nonmethane noncondensibles), ethane, formaldehyde, and unsaturated hydrocarbons (e.g., ethylene).

[f] The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is an EPA recommended guideline for meeting the primary ambient air quality standard for oxidants.

[g] Methane and hydrogen are simple asphyxiants; have no TLV or F, and therefore no S.

[h] Value for carcinogenic compounds adopted for this program. It corresponds approximately to the minimum detectable limit.

assumed earlier and the following assumptions for application of control: 25% of batch kilns are controlled, and 100% of both continuous furnaces and briquetting plants are controlled. Results are presented in Table 10 (36).

TABLE 10. ESTIMATED NATIONAL EMISSIONS FROM CHARCOAL PRODUCTION (metric tons)

Species	Estimated charcoal industry emissions in 1975[a]			National emissions from all sources in 1972 (36)
	Batch kilns	Continuous furnaces	Briquetting	
Particulate[b]	5.9×10^3 to 8.5×10^4	4.6×10^2 to 6.6×10^3	2.1×10^2 to 1.2×10^3	17,872,000
Carbon monoxide	3.3×10^4 to 3.7×10^4	2.6×10^3 to 2.9×10^3	—[c]	96,868,000
Methanol	1.4×10^4 to 1.6×10^4	1.1×10^3 to 1.2×10^3	—[c]	
Acetic acid	2.1×10^4 to 2.4×10^4	1.7×10^3 to 1.9×10^3	—[c]	25,045,000[d]
Other gases[e]	1.5×10^3 to 1.3×10^4	1.1×10^2 to 9.8×10^2	—[c]	[f]
Methane	9.2×10^3 to 1.2×10^4	7.1×10^3 to 9.3×10^3	—[c]	—[f]
Hydrogen	1.1×10^2 to 4.2×10^2	8.1×10^0 to 3.3×10^1	—[c]	—
Nitrogen oxides	3.2×10^3	4.1×10^3	—[c]	22,258,000
Polycyclic organic materials	0.8	0.7	—[c]	—[f]

[a] Controlled emissions based on assumptions presented in the text.

[b] Includes tar, oil, and pyroacids.

[c] No information.

[d] Total national hydrocarbon emissions.

[e] Includes compounds identified in the literature as "higher hydrocarbons" (assumed to be nonmethane noncondensibles), ethane, formaldehyde, and unsaturated hydrocarbons (e.g., ethylene).

[f] Not applicable.

Estimated emissions (based on controlled emission factors) are responsible for an estimated 0.04% to 0.5% of national particulate emissions, less than 0.1% of national carbon monoxide emissions, 0.02% to 0.2% of national hydrocarbon emissions, and less than 0.1% of national nitrogen oxide emissions. Estimated charcoal emissions for 1975 were compared with total national emissions from all sources for 1972.

The same evaluation procedure can be followed for each charcoal-producing state for which production was identified by apportioning state emissions according to each state's share of national charcoal production. Results are given in Table 11. As above, 1975 charcoal emissions are compared to 1972 statewide total emissions.

Using the average population density around a charcoal plant, one can determine an affected population, defined as the number of persons around a representative source exposed to emission concentrations that cause the ratio of $\overline{\chi}/F$ to exceed 0.1 or 1.0. Plume

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(36) 1972 National Emissions Report; National Emissions Data Systems (NEDS) of the Acrometric and Emissions Reporting System (AEROS). EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

TABLE 11. ESTIMATED CONTROLLED CRITERIA EMISSIONS BY STATE

State	Fraction of national production, %[a]	Estimated controlled criteria emissions, metric ton/yr			
		Charcoal manufacture emissions 1975 / All emissions 1972 (36)			
		Particulate[b]	Carbon monoxide	Hydrocarbon[c]	Nitrogen oxides
Arkansas	9	$\frac{6.2 \times 10^2 \text{ to } 8.9 \times 10^3}{137,817}$ or <1% to 6%	$\frac{3.5 \times 10^3 \text{ to } 3.9 \times 10^3}{843,234}$ or <1%	$\frac{3.8 \times 10^3 \text{ to } 5.4 \times 10^3}{195,538}$ or 2% to 3%	$\frac{7.0 \times 10}{168,989}$ or <1%
California	5	$\frac{3.6 \times 10^2 \text{ to } 5.1 \times 10^3}{1,006,452}$ or <1%	$\frac{2.0 \times 10^3 \text{ to } 2.2 \times 10^3}{8,237,667}$ or <1%	$\frac{2.2 \times 10^3 \text{ to } 3.1 \times 10^3}{2,160,710}$ or <1%	$\frac{4.0 \times 10^2}{1,663,139}$ or <1%
Maryland	1	$\frac{7.8 \times 10^1 \text{ to } 1.1 \times 10^3}{494,921}$ or <1%	$\frac{4.3 \times 10^2 \text{ to } 4.8 \times 10^2}{1,261,804}$ or <1%	$\frac{4.8 \times 10^2 \text{ to } 6.8 \times 10^2}{295,867}$ or <1%	$\frac{8.8 \times 10^1}{265,204}$ or <1%
Minnesota	2	$\frac{1.2 \times 10^2 \text{ to } 1.6 \times 10^3}{266,230}$ or <1%	$\frac{6.4 \times 10^2 \text{ to } 7.2 \times 10^2}{170,749}$ or <1%	$\frac{7.0 \times 10^2 \text{ to } 1.0 \times 10^3}{410,674}$ or <1%	$\frac{1.3 \times 10^2}{311,834}$ or <1%
Mississippi	4	$\frac{2.4 \times 10^2 \text{ to } 3.4 \times 10^3}{168,355}$ or <1% to 2%	$\frac{1.3 \times 10^3 \text{ to } 1.5 \times 10^3}{829,094}$ or <1%	$\frac{1.5 \times 10^3 \text{ to } 2.1 \times 10^3}{195,950}$ or <1% to 1%	$\frac{2.7 \times 10^2}{172,519}$ or <1%
Missouri	45	$\frac{2.9 \times 10^3 \text{ to } 4.2 \times 10^4}{202,435}$ or 1% to 21%	$\frac{1.6 \times 10^4 \text{ to } 1.8 \times 10^4}{1,854,901}$ or <1%	$\frac{1.8 \times 10^4 \text{ to } 2.5 \times 10^4}{413,130}$ or 5% to 6%	$\frac{3.3 \times 10^3}{448,300}$ or <1%
North Dakota	7	$\frac{4.7 \times 10^2 \text{ to } 6.7 \times 10^3}{78,978}$ or <1% to 8%	$\frac{2.6 \times 10^3 \text{ to } 2.9 \times 10^3}{318,679}$ or <1%	$\frac{2.9 \times 10^3 \text{ to } 4.1 \times 10^3}{70,289}$ or 5% to 6%	$\frac{5.3 \times 10^2}{85,708}$ or <1%
Ohio	12	$\frac{7.6 \times 10^2 \text{ to } 1.1 \times 10^4}{1,766,056}$ or <1%	$\frac{4.2 \times 10^3 \text{ to } 4.7 \times 10^3}{5,205,719}$ or <1%	$\frac{4.6 \times 10^3 \text{ to } 6.6 \times 10^3}{1,153,493}$ or <1%	$\frac{8.6 \times 10^2}{1,101,470}$ or <1%
Oklahoma	2	$\frac{1.3 \times 10^2 \text{ to } 1.9 \times 10^3}{93,595}$ or <1% to 2%	$\frac{7.3 \times 10^2 \text{ to } 8.2 \times 10^2}{1,456,627}$ or <1%	$\frac{8.1 \times 10^2 \text{ to } 1.2 \times 10^3}{341,358}$ or <1%	$\frac{1.5 \times 10^2}{222,687}$ or <1%
South Carolina	2	$\frac{1.5 \times 10^2 \text{ to } 2.2 \times 10^3}{198,767}$ or <1% to 1%	$\frac{8.4 \times 10^2 \text{ to } 9.5 \times 10^2}{4,222,168}$ or <1%	$\frac{9.3 \times 10^2 \text{ to } 1.3 \times 10^3}{907,833}$ or <1%	$\frac{1.7 \times 10^2}{521,544}$ or <1%
Tennessee	3	$\frac{1.7 \times 10^2 \text{ to } 2.4 \times 10^3}{409,704}$ or <1%	$\frac{9.2 \times 10^2 \text{ to } 1.0 \times 10^3}{1,469,253}$ or <1%	$\frac{1.0 \times 10^3 \text{ to } 1.5 \times 10^3}{362,928}$ or <1%	$\frac{1.9 \times 10^2}{426,454}$ or <1%
Virginia	7	$\frac{4.4 \times 10^2 \text{ to } 6.3 \times 10^3}{477,494}$ or <1% to 1%	$\frac{2.4 \times 10^3 \text{ to } 2.7 \times 10^3}{1,548,031}$ or <1%	$\frac{2.7 \times 10^3 \text{ to } 3.8 \times 10^3}{369,416}$ or <1% to 1%	$\frac{5.0 \times 10^2}{329,308}$ or <1%
Wisconsin	1	$\frac{6.4 \times 10^1 \text{ to } 9.1 \times 10^2}{411,558}$ or <1%	$\frac{3.5 \times 10^2 \text{ to } 4.0 \times 10^2}{1,582,869}$ or <1%	$\frac{3.9 \times 10^2 \text{ to } 5.6 \times 10^2}{523,930}$ or <1%	$\frac{7.2 \times 10^1}{408,525}$ or <1%

[a] Based on Appendix A.

[b] Includes tar, oil, and pyroacids.

[c] Methanol, acetic acid, and other gases summed and compared to state hydrocarbon emissions.

dispersion calculations (Equation 5.13, Reference 30) determine the two downwind distances for which the ratio equals 0.1 or 1.0 (see Figure 4). These two distances are used to calculate an annular area around the representative sources. The affected population is calculated by multiplying these areas by the average population density around a charcoal plant. The average population density used (11 persons/km^2) was the average for the 21 charcoal-producing counties in Missouri (18), the largest charcoal-producing state (45%). Results of these calculations using controlled emission factors are presented in Table 12.

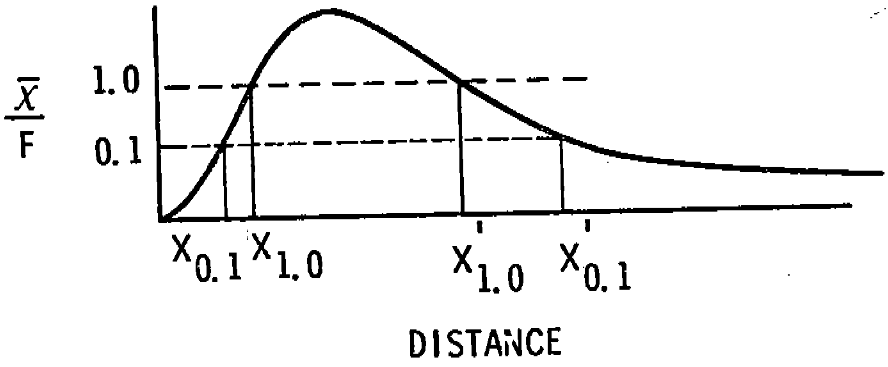

Figure 4. General distribution of $\overline{X}/F$ as a function of distance from the source, showing the two general roots to the plume dispersion equation.

TABLE 12. AFFECTED POPULATION AROUND CONTROLLED REPRESENTATIVE CHARCOAL MANUFACTURING SOURCES

	Affected population, number of persons					
	Batch kiln		Continuous furnace		Briquetting	
Emission	$\frac{\overline{X}}{F}>0.1$	$\frac{\overline{X}}{F}>1.0$	$\frac{\overline{X}}{F}>0.1$	$\frac{\overline{X}}{F}>1.0$	$\frac{\overline{X}}{F}>0.1$	$\frac{\overline{X}}{F}>1.0$
Particulate[a]	<1 to 10	0[b] to <1	6 to 147	0 to 11	2 to 12	<1
Carbon monoxide	0	0	0	0	—[c]	—[c]
Methanol	<1	0	3 to 4	0	—[c]	—[c]
Acetic acid	8 to 9	<1	113 to 130	8 to 9	—[c]	—[c]
Other gases[d]	<1 to 2	0 to <1	0 to 31	0	—[c]	—[c]
Methane	—[e]	—[e]	—[e]	—[e]	—[c]	—[c]
Hydrogen	—[e]	—[e]	—[e]	—[e]	—[c]	—[c]
Nitrogen oxides	5	<1	247	20	—[c]	—[c]
Polycyclic organic materials	8	<1	111	8	—[c]	—[c]

[a] Includes tar, oil, and pyroacids.

[b] Zero indicates $\overline{X}/F$ is never greater than the stated value, 0.1 or 1.0.

[c] No information.

[d] Includes compounds identified in the literature as "higher hydrocarbons" (assumed to be nonmethane noncondensibles), ethane, formaldehyde, and unsaturated hydrocarbons (e.g., ethylene).

[e] Methane and hydrogen are simple asphyxiants, have to TLV or F, and therefore, no affected population.

SECTION 5

EMISSION CONTROL TECHNOLOGY

Application of emission control technology for charcoal manufacture in the past has been primarily a function of process economics. As long as byproduct recovery of methanol and acetic acid was profitable, the practice was commonplace. When the economics deteriorated, byproduct recovery declined and finally ceased. Following is a discussion of current emission control practices as applied to batch and continuous charcoal production and charcoal briquetting operations.

BATCH PRODUCTION

Control of emissions from charcoal kilns is difficult due to the cyclic nature of the process and therefore the emissions. Throughout the cycle, both emission composition (see Section 3) and flow rate change. Typically, emission rates peak early in the cycle at an actual flow rate over 40% greater than the actual flow rate near the end of the cycle (19). Variation in feed material and operating practice also influence emission composition and rate.

Two conventional emission control techniques are applicable to charcoal kilns: scrubbing or incineration. Scrubbing can be dismissed for two technical reasons. First, most small charcoal kilns are located in remote areas frequently not having ready access to adequate cooling water. Second, collected emissions would then represent a liquid waste problem since byproduct processing and recovery equipment would not be economical. The other alternative, incineration using an afterburner, is technically more promising.

A direct-fired afterburner, capable of incinerating the combustible emissions by subjecting them to direct flame contact for a sufficient time and at a sufficient temperature, provides the most feasible means for emission control. Incinerators for this application were designed, installed, and operated by Husky Briquetting, Inc., on kilns in Wisconsin and Minnesota. Figure 5 presents a schematic diagram of an incinerator capable of serving multiple kilns. The incinerator is equipped with two oil or natural gas burners which are required for the first 24 hr of the cycle, when most of the moisture in the feed material is driven off. Combustion is then self-sustaining. Charcoal kiln

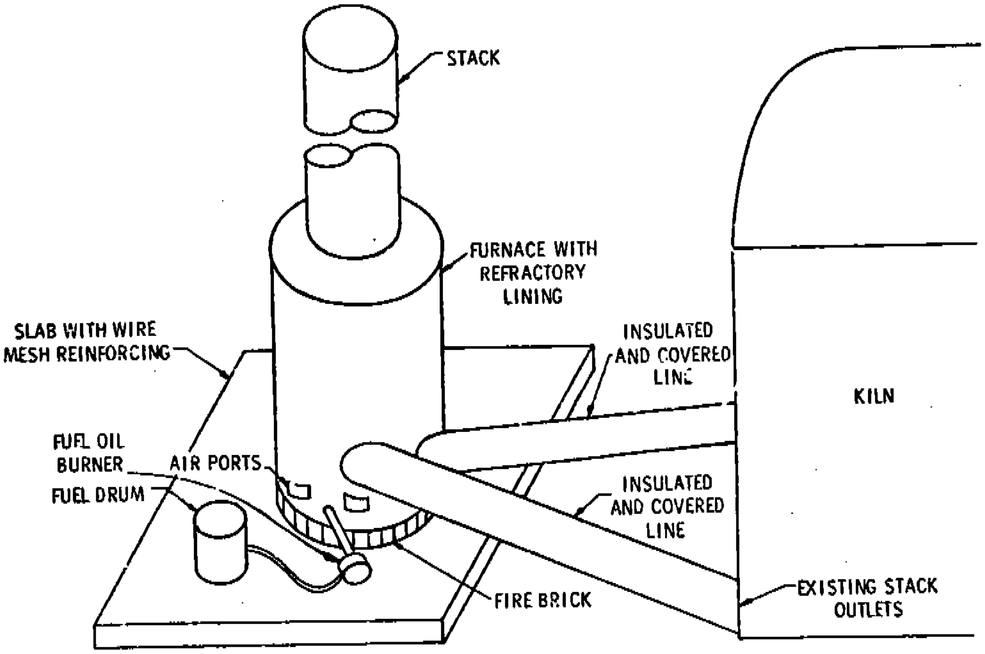

Figure 5. Schematic of charcoal emission incinerator (13).

emissions have been reduced an estimated 80% to 90% using this type of equipment (13, 17). Efficient afterburning would probably effectively reduce emissions of the species listed in Table 5.

Analysis of the economics of a typical kiln operation performed for the Missouri Air Conservation Commission indicates why the application of afterburners is not widespread. The typical operation was defined as approximately 12 "Missouri-type" kilns with an annual production of 2,400 metric tons of charcoal. The net profit for an uncontrolled facility was an estimated $1.57/metric ton. Installation and operation of afterburners for this facility would cost $2.57/metric ton, yielding a net loss for controlled operation of $1.00/metric ton. Consequently, afterburners do not appear to be economically feasible for a typical operation under the assumed market conditions (13).

CONTINUOUS PRODUCTION

Continuous production of charcoal is more amenable to emission control than batch kilns. Being continuous, emission composition and flow rate are relatively constant. Normally, the off-gas is burned in refractory-lined stacks by opening adjustable doors in the base of the stack to admit combustion air. The stack emits flame and a light smoke of intensity below Ringelmann Number 2 and usually below Ringelmann Number 1 (personal communication, A. W. Seeds, Charcoal Briquet Institute, 31 August 1977). Where better emission control is required, a fan draws the gases through a chamber for afterburning. They are then scrubbed with water and exhausted to the atmosphere (5, 14, 20, 23). Incineration is estimated to reduce emissions 95% (personal communication, B. L. Winter, Clorox Company, 26 August 1977), and efficient afterburning would probably effectively destroy the species listed in Table 6.

Energy recovered from combustible pyrolysis gases can be used in numerous ways. An estimated average of 29 GJ can be obtained for each metric ton of charcoal produced (14). This energy has been used to fire a wood predryer, briquet dryer, or to generate steam (20, 37). Other potential applications for this energy include running a high energy process such as lime calcining in conjunction with charcoal manufacture or generating electricity from a turbine-driven generator (14).

Although not documented, it is believed that all continuous charcoal producing facilities have some type of pyrolysis gas emission control, principally afterburning.

BRIQUETTING

Little information was found concerning emission control equipment on briquet dryers. Two sources from a National Emissions Data System (NEDS) listing were specifically identified as briquetting operations. One had centrifugal collection and the other had fabric filtration with respectively 65% and 99% particulate collection (32).

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(37) New Charcoal Plant Uses Flue Gas as Fuel. Wood and Wood Products, 69(9):35-36, 1964.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

Charcoal consumption is directly related to leisure time activities since its primary use is as a recreational fuel. Industry growth is expected to accelerate in the 1970's "since a greater percentage of the population will be in their prime charcoal cooking years (25)." Estimates of future industry growth range from an annual increase of 2% to 15% (personal communication, A. W. Seeds, Charcoal Briquet Institute, 27 February 1976) (20, 25-27). An annual growth rate near the low end of the range, 4%, is assumed due to the accelerating growth of competing gas and electric grills for outdoor cooking (personal communication, A. W. Seeds, Charcoal Briquet Institute, 31 August 1977). Applying an annual growth rate of 4% to 1975 estimated production of 590,000 metric tons charcoal yields a 1980 estimated production rate of 720,000 metric tons charcoal. If the level of application and efficiency of control remain constant, this growth rate will result in a 22% growth in emissions from 1975 to 1980.

Even with this predicted growth, the trend of the recent past toward fewer but larger producers will probably continue. Requirements for additional emission control equipment would accelerate this trend via small plant closures due to an additional economic burden on already marginal economics of the small kiln operations (13, 20).

Potential for future changes in the charcoal manufacturing industry is suggested by the many historical changes to date in the industry. For example, a shift in economics or raw material availability could potentially encourage byproduct methanol or acetic acid recovery again some time in the future. In fact, discussing future acetic acid production, one reference suggests that "feedstock availability may be more important than relative cost (38)."

At one location, charcoal manufacture has become a byproduct again. One hardwood flooring plant produces its entire steam supply for its drying kilns and other heating needs by burning the combustible gases distilled from dry wood residues (22). The resulting charcoal produced is merely a byproduct.

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(38) Acetic Output: Ample for Now. Short by 1980? Chemical Week, 117(6):23-24, 1975.

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APPENDIX A

CHARCOAL PRODUCERS IN THE UNITED STATES

TABLE A-1. CHARCOAL PRODUCERS IN THE UNITED STATES

State	Number	City or county	Producer	Annual production, metric tons	Reference
Alabama	1	Dothan	Kingsford Co.	907 to 4,535	39,40
	2	Tuscumbia	Malone Charcoal Co.	–[a]	39
	3	Muscle Shoals	McKinney Lumber & Plywood	–[a]	39
TOTAL				0	
Arkansas	4	Jasper	Jasper Charcoal Co.	4,960	32,39,41
	5	Huntsville	Keeter Charcoal Co.	5,950	32,39,41
	6	Omaha	Keeter Charcoal Co.	3,700	32,41
	7	Green Forest	Keeter Charcoal Co.	5,210	32,41
	8	Yellville	Martin Charcoal Co.	2,000	32,39
	9	Paris	Ozark Charcoal Co.	4,000	32,39,41
	10	Scranton	Scranton Charcoal Co.	2,770	32,39,41
	11	Waldron	Waldron Charcoal Co.	3,600	32,39,41
	12	Harrison	Newberry Charcoal Co.	–[a]	–[b]
	13	Paris	Paris Charcoal Co.	4,000	32
	14	Paris	Arkansas Charcoal Co.	–[a]	41
	15	Hot Springs	Weyerhaeuser Co.	–[a]	–[b]
	16	George	George Charcoal Co.	–[a]	41
	17	Hatfield	Arkansas Charcoal Co.	–[a]	41
	18	Waldron	Waldron Charcoal Co.	3,680	32,41
	19	Mountain View	Hinesley & Everett Enterprises	–[a]	41
TOTAL				4,000[c]	
California	20	Elk Grove	C. B. Hobbs Corp.	23,000	32,39
	21	Santa Clara	C. B. Hobbs Corp.	–[a]	–[b]
	22	Milipitas	C. B. Hobbs Corp.	–[a]	32
TOTAL				23,000	
Florida	23	Ocala	Pioneer Charcoal	–[a]	32
TOTAL				0	
Georgia	24	Atlanta	Husky Industries	–[a]	–[b]
TOTAL				0	
Kansas	25	Chetopa	Jayhawk Charcoal Co.	–[a]	–[b]
TOTAL				0	
Kentucky	26	Burnside	Kingsford Co.	–[a]	–[b]
TOTAL				0	
Illinois	27	Chicago	Great Lakes Carbon Corp.	–[a]	–[b]
TOTAL				0	
Maryland	28	White Church	Kingsford Co.	5,000	32
	29	Oakland	Kingsford Co.	0	39
TOTAL				5,000	
Minnesota	30	Isanti	Husky Briquetting, Inc.	7,400	32
TOTAL				7,400	
Mississippi	31	Bruce	Blackjack Charcoal Co.	–[a]	32,39
	32	Pachuta	Hood Charcoal Co.	15,300	32,39
	33	Pachuta	Masonite Corp., Charcoal Div.	–[a]	–[b]
	34	Beaumont	Ronnies Hickory Chips	–[a]	42
TOTAL				15,300	
Missouri	35	Barry[d]	Harris Enterprises	3,000	32
	36	Purdy	Heaser Charcoal Co.	907 to 4,535[e]	18
	37	Boone[d]	Charles Chrisman Charcoal	3,000	32
	38	Centralia	L & A Dailing Charcoal Co.	907 to 4,535[e]	18
	39	Carter[d]	Big Springs Industrial	3,000	32
	40	Carter[d]	Carter County Charcoal	3,000	32
	41	Ellsinore	Leach Bros. Charcoal	1,460	18,32
	42	Ellsinore	Rozark Farms	5,000	18,32
	43	Van Buren	Big Springs Charcoal	1,400	32

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[a] Data not available. [b] Personal communication, A. W. Seeds, Charcoal Briquet Institute, February 27, 1976.

[c] Numbers do not add due to rounding. [d] Counties. [e] Capacity range rather than production.

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TABLE A-1 (continued)

State	Number	City or county	Producer	Annual production, metric tons	Reference
Missouri (continued)	44	Van Buren	Big Springs Charcoal	907 to 4,535[e]	19
	45	Cole	Stegeman Charcoal Co.	3,000	32
	46	Henley	Louis Stegeman Charcoal Co.	907 to 4,535[e]	18
	47	Jefferson City	Rich Stegeman Charcoal Co.	907 to 4,535[e]	18
	48	Steelville	Hardwood Charcoal Co.	3,000	18,32
	49	Wesco	Foidell Development Corp.	907 to 4,535[e]	18
	50	Greenfield	Pringle Charcoal Co.	3,000	18,32
	51	Salem	Carty Charcoal	168	18,32
	52	Salem	Floyd Charcoal Co.	35,700	18,32
	53	Salem	C & H Charcoal	68	32
	54	Dent[d]	Langworthy Charcoal Co.	3,000	32
	55	Dent[d]	Lennox Charcoal Co.	3,000	32
	56	Salem	Wieberg Charcoal Co.	3,000	18,32
	57	Salem	Hobson Charcoal Co.	230	18,32
	58	Gasconade[d]	Hickory Charcoal Co.	3,000	32
	59	Owensville	Gene's Charcoal	907 to 4,535[e]	18
	60	Wheatland	J & E Charcoal Co.	907 to 4,535[e]	18
	61	Howell[d]	Missouri Charcoal Co.	3,000	32
	62	Mount View	Craig Charcoal Co.	5,000	18,32
	63	West Plains	Nubbin Ridge Charcoal Co.	3,000	18,32
	64	Mount View	Bays Sawmill and Charcoal	420	18,32
	65	Peace Valley	Peace Valley Kilns	4,670	18,32
	66	Mount View	Old Hickory Charcoal Co.	454 to 906[e]	18[b]
	67	Mount View	Kerr Forest Products	907 to 4,535[e]	18
	68	Kansas City	Standard Milling Co.	–[b]	–[b]
	69	Hocomo	Bakersfield Charcoal Co.	907 to 4,535[e]	18
	70	Laclede[d]	Independent Stave Co.	1,390	32
	71	Laclede[d]	Timber Products Co.	3,000	32
	72	Vienna	Wulff Charcoal Co.	8,700	18,32
	73	High Gate	Kingsford Co.	8,700	18,32
	74	Belle	Kingsford Co.	–[b]	25,40
	75	Belle	K. B. Stockton	907 to 4,535[e]	18
	76	Belle	H & D Charcoal	454 to 906[e]	18
	77	Hayden	Curtis & Hayes Charcoal	454 to 906[e]	18
	78	Iberia	Louis Stegeman Charcoal	3,800	18,32
	79	Miller[d]	Kalaf Charcoal	3,000	32
	80	St. Elizabeth	Kirkweg Charcoal Co.	110	18,32
	81	Neosho	Neosho Charcoal Products	3,000	18,32
	82	Oregon[d]	Greer Springs Co.	3,000	18,32
	83	Meta	Barnhart Charcoal	3,000	18,32
	84	Osage[d]	J & M Charcoal Co.	3,000	32
	85	Osage[d]	Kelly Charcoal Co.	3,000	32
	86	Freeburg	Al Luecke Charcoal Co.	907 to 4,535[e]	18,32
	87	Osage[d]	McDonald Charcoal Co.	3,000	32
	88	Osage[d]	Ridenhour Charcoal Co.	3,000	32
	89	Meta	Ripka Charcoal and Lumber	–[a]	18,32
	90	Osage[d]	Sugar Creek Charcoal Co.	3,000	32
	91	Freeburg	Wieberg Charcoal Co.	3,000	18,32
	92	Freeburg	Ben Berhorst	907 to 4,535[e]	18
	93	Meta	Charkol, Inc.	907 to 4,535[e]	18
	94	Belle	Gene Noblett Charcoal Co.	454 to 906[e]	18
	95	Meta	Standard Milling Co.	–[a]	39
	96	Gainesville	Ozark Forest Charcoal	5,000	18,32
	97	Ozark[d]	Wallace Charcoal Co.	3,000	32
	98	St. James	Parry Charcoal Co.	3,000	18,32
	99	Lake Spring	Lenox Charcoal	907 to 4,535[e]	18
	100	Vienna	Tackett Charcoal Co.	3,000	18,32
	101	Lesterville	Black River Charcoal Co.	907 to 4,535[e]	18,32
	102	Reynolds	Copeland Charcoal Co.	1,230	18,32
	103	Winona	Dailey Charcoal	122	18,32
	104	Shannon[d]	George Helruth Charcoal	3,000	32
	105	Shannon[d]	Royal Forest Charcoal	2,300	32
	106	Birch Tree	Kerr Charcoal	907 to 4,535[e]	18
	107	Summersville	Craig Charcoal	9,000	18,32
	108	Round Springs	Roaring Springs Corp.	900	32
	109	Round Springs	Round Springs Charcoal	907 to 4,535[e]	18
	110	Pound Springs	Robert Hamilton	907 to 4,535[e]	18
	111	Gladden	Timber Charcoal Co.	2,000	32
	112	Branson	S & S Charcoal Co.	5,000	18,32
	113	Bradleyville	Horner Charcoal Co.	4,200	18,32
	114	Branson	Keeter Charcoal Co.	–[a]	19
	115	Raymondville	Thomason Charcoal Co.	2,690	18,32
	116	Licking	Wulff Charcoal Co.	5,000	18,32
	117	Plato	H. O. Charcoal Co.	907 to 4,535[a]	18

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[a] Data not available. [b] Personal communication, A. W. Seeds, Charcoal Briquet Institute, February 27, 1976. [c] Numbers do not add due to rounding. [d] Counties. [e] Capacity range rather than production.

(continued)

TABLE A-1 (continued)

State	Number	City or county	Producer	Annual production, metric tons	Reference
Missouri (continued)	118	Seymour	Oak-lite Corp.	2,000	18,32
	119	St. Louis	Cupples Co., Manufacturers	—[a]	—[b]
TOTAL				190,000[f]	
New Jersey	120	Teterboro	Degussa, Inc.	—[a]	—[b]
TOTAL				0	
North Dakota	121	Dickinson	Husky Industries	30,000	32,39
TOTAL				30,000	
Ohio	122	Oak Hill	Victory Charcoal Co.	1,100	32,39
	123	Lucas[d]	Sun Oil Co.	7,690	32
	124	West Marion	Great Lakes Carbon	40,000	32
	125	McArthur	Roseville Charcoal	—[a]	32
TOTAL				49,000	
Oklahoma	126	Heavener	Forest Products Charcoal Co.	8,000	32,39,43
	127	Talihina	Forest Products Charcoal Co.	477	32,39
	128	Clayton	Forest Products Charcoal Co.	—[a]	39
	129	Talihina	Talihina Charcoal Co.	—[a]	43
	130	Bull Hollow	Cherokee Forest Industries	—[a]	43
TOTAL				8,000[c]	
Oregon	131	Springfield	Kingsford Co.	—[a]	25,39,40
	132	White City	Georgia Pacific Corp.	—[a]	—[b]
TOTAL				0	
Pennsylvania	133	Brookville	Humphrey Charcoal	—[a]	39
TOTAL				0	
South Carolina	134	Lake City	T. S. Ragsdale Co., Inc.	9,720	8,32[b]
TOTAL				9,720	
Tennessee	135	Jamestown	Royal Oak Charcoal Co.	10,700	32,44
	136	Red Bank	Cumberland Kingsford	—[a]	39
	137	Cookeville	Royal Oak Charcoal Co.	—[a]	32
	138	Tullahoma	Tennessee Dickel Distilling	—[a]	44
	139	Red Boiling Springs	Cumberland Charcoal Corp.	—[a]	44
	140	Spencer	Royal Oak Charcoal Co.	—[a]	39,44
	141	Memphis	Arkansas Charcoal Co.	—[a]	—[b]
	142	Lynchburg	Jack Daniels Distillery	—[a]	32,44
TOTAL				10,700	
Texas	143	Platonia	B & B Charcoal	—[a]	39
	144	Houston	Pine-O-Pine Co.	—[a]	—[b]
	145	Jacksonville	Campfire Charcoal Co.	—[a]	39
	146	Jacksonville	Char Time Charcoal	—[a]	39
	147	San Antonio	National Charcoal Co.	—[a]	39
TOTAL				0	
Virginia	148	Kenbridge	Imperial Briquet Corp.	28,200	32,39[b]
TOTAL				28,200	
West Virginia	149	Belington	Kingsford Charcoal	—[a]	39
	150	Beryl	Kingsford Charcoal	—[a]	25,39,40
	151	Maysville	Kingsford Charcoal	—[a]	32
	152	Parsons	Kingsford Charcoal	—[a]	25,32,40
	153	Swiss	Roseville Charcoal	—[a]	39
	154	Bentree	Roseville Charcoal	—[a]	39
TOTAL				0	
Wisconsin	155	Hixton	Husky Industries	4,100	32
TOTAL				4,100	
UNITED STATES				420,000[c]	

[a] Data not available. [b] Personal communication, A. W. Seeds, Charcoal Briquet Institute, February 27, 1976.
[c] Numbers do not add due to rounding. [d] Counties. [f] Total state production is assumed to be 125,078 metric tons from Reference 18 plus production from other references for Missouri plants.

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(43) Bertelson, D. F. Oklahoma Forest Industries, 1972. Forest Service Resource Bulletin SO-45, U.S. Department of Agriculture, New Orleans, Louisiana, 1973. p. 16.

(44) Bertelson, D. F. Tennessee Forest Industries. Forest Service Resource Bulletin SO-30, U.S. Department of Agriculture, New Orleans, Louisiana, 1971. pp. 25-26.

APPENDIX B

DERIVATION OF SOURCE SEVERITY EQUATIONS

SUMMARY OF SEVERITY EQUATIONS

The severity (S) of pollutants may be calculated using the mass emission rate, Q, the height of the emissions, H, and the threshold limit value, TLV (45). The equations summarized in Table B-1 are developed in detail in this appendix.

TABLE B-1. POLLUTANT SEVERITY EQUATIONS FOR ELEVATED POINT SOURCES

Pollutants	Severity equation
Particulate	$S = \frac{70\ Q}{H^2}$
SO_x	$S = \frac{50\ Q}{H^2}$
NO_x	$S = \frac{315\ Q}{H^{2.1}}$
Hydrocarbon	$S = \frac{162\ Q}{H^2}$
CO	$S = \frac{0.78\ Q}{H^2}$
Other	$S = \frac{5.5\ Q}{TLV \cdot H^2}$

DERIVATION OF χ_{max} FOR USE WITH U.S. AVERAGE CONDITIONS

The most widely accepted formula for predicting downwind ground level concentrations from a point source is (35)

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{(B-1)}$$

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(45) TLV® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. 94 pp.

where χ = downwind ground level concentration at reference coordinate x and y with emission height of H, g/m^3
Q = mass emission rate, g/s
π = 3.14
σ_y = standard deviation of horizontal dispersion, m
σ_z = standard deviation of vertical dispersion, m
u = wind speed, m/s
y = horizontal distance from centerline of dispersion, m
H = height of emission release, m
x = downwind dispersion distance from source of emission release, m

We assume that χ_{max} occurs when x is much greater than 0 and y equals 0. For a given stability class, standard deviations of horizontal and vertical dispersion have often been expressed as a function of downwind distance by power law relationships as follows (46):

$$\sigma_y = ax^b \tag{B-2}$$

$$\sigma_z = cx^d + f \tag{B-3}$$

Values for a, b, c, d, and f are given in Tables B-2 and B-3. Substituting these general equations into Equation B-1 yields

$$\chi = \frac{Q}{ac\pi ux^{b+d} + a\pi ufx^b} \exp\left[-\frac{H^2}{2(cx^d + f)^2}\right] \tag{B-4}$$

Assuming that χ_{max} occurs at x less than 100 m or the stability class is C, then f equals 0 and Equation B-4 becomes

$$\chi = \frac{Q}{ac\pi ux^{b+d}} \exp\left[\frac{-H^2}{2c^2x^{2d}}\right] \tag{B-5}$$

For convenience, let

$$A_R = \frac{Q}{ac\pi u} \text{ and } B_R = \frac{-H^2}{2c^2}$$

so that Equation B-5 reduces to

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(46) Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

TABLE B-2. VALUES OF a FOR THE COMPUTATION OF σ_y[a] (47)

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

[a] For the equation

$$\sigma_y = ax^b$$

where x = downwind distance
b = 0.9031 (from Reference 48)

TABLE B-3. VALUES OF THE CONSTANTS USED TO ESTIMATE VERTICAL DISPERSION[a] (47)

Usable range, m	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	f_3
<100	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.8[illegible]	0
	F	0.053	0.8[illegible]	0

[a] For the equation

$$\sigma_z = cx^d + f$$

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(47) Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11):859-863, 1972.

(48) Tadmor, J., and Y. Gur. Analytical Expressions for the Vertical and Lateral Dispersion Coefficients in Atmospheric Diffusion. Atmospheric Environment, 3(6):688-689, 1969.

$$\chi = A_R x^{-(b+d)} \exp\left[\frac{B_R}{x^{2d}}\right] \qquad \text{(B-6)}$$

Taking the first derivative of Equation B-6

$$\frac{d\chi}{dx} = A_R \left\{ x^{-b-d} \left(\exp\left[B_R x^{-2d}\right]\right) \left(-2dB_R x^{-2d-1}\right) + \exp\left[B_R x^{-2d}\right] \left(-b-d\right) x^{-b-d-1} \right\} \qquad \text{(B-7)}$$

and setting this equal to zero (to determine the roots which give the minimum and maximum conditions of χ with respect to x) yields

$$\frac{d\chi}{dx} = 0 = A_R x^{-b-d-1} \left(\exp\left[B_R x^{-2d}\right]\right) \left[-2dB_R x^{-2d} - b - d\right] \qquad \text{(B-8)}$$

Since we define that $x \neq 0$ or ∞ at χ_{max}, the following expression must be equal to 0.

$$-2dB_R x^{-2d} - d - b = 0 \qquad \text{(B-9)}$$

or

$$(b+d) x^{2d} = -2dB_R \qquad \text{(B-10)}$$

or

$$x^{2d} = \frac{-2dB_R}{b+d} = \frac{2dH^2}{2c^2(b+d)} \qquad \text{(B-11)}$$

or

$$x^{2d} = \frac{dH^2}{c^2(b+d)} \qquad \text{(B-12)}$$

or

$$x = \left(\frac{dH^2}{c^2(b+d)}\right)^{\frac{1}{2d}} \text{ at } \chi_{max} \qquad \text{(B-13)}$$

Thus Equations B-2 and B-3 become

$$\sigma_y = a\left(\frac{dH^2}{c^2(d+b)}\right)^{\frac{b}{2d}} \qquad \text{(B-14)}$$

$$\sigma_z = c\left(\frac{dH^2}{c^2(b+d)}\right)^{\frac{d}{2d}} = \left(\frac{dH^2}{b+d}\right)^{\frac{1}{2}} \qquad \text{(B-15)}$$

The maximum will be determined for U.S. average conditions of stability. According to Gifford (49), this is when σ_y equals σ_z.

Since b equals 0.9031, and upon inspection of Table B-2 under U.S. average conditions, σ_y equals σ_z, it can be seen that 0.881 is less than or equal to d which is less than or equal to 0.905 (class C stability[a]). Thus, it can be assumed that b is nearly equal to d or

$$\sigma_z = \frac{H}{\sqrt{2}} \qquad \text{(B-16)}$$

and

$$\sigma_y = \frac{a}{c}\,\frac{H}{\sqrt{2}} \qquad \text{(B-17)}$$

Under U.S. average conditions, σ_y equals σ_z and a approximates c if b approximates d and f equals 0 (between class C and D, but closer to belonging in class C).

Then

$$\sigma_y = \frac{H}{\sqrt{2}} \qquad \text{(B-18)}$$

Substituting for σ_y and σ_z into Equation B-1 and letting y equal 0

$$\chi_{max} = \frac{2\ Q}{\pi u H^2}\exp\left[-\frac{1}{2}\left(\frac{H\sqrt{2}}{H}\right)^2\right] \qquad \text{(B-19)}$$

or

$$\chi_{max} = \frac{2\ Q}{\pi e u H^2} \qquad \text{(B-20)}$$

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[a] The values given in Table B-3 are mean values for stability class. Class C stability describes these coefficients and exponents, only within about a factor of two (35).

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(49) Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 113.

For U.S. average conditions, u equals 4.47 m/s so that Equation B-20 reduces to

$$\chi_{max} = \frac{0.0524\ Q}{H^2} \qquad \text{(B-21)}$$

DEVELOPMENT OF SOURCE SEVERITY EQUATIONS

The general source severity, S, relationship has been defined as follows:

$$S = \frac{\bar{\chi}_{max}}{F} \qquad \text{(B-22)}$$

where $\bar{\chi}_{max}$ = time-averaged maximum ground level concentration
F = hazard factor

Noncriteria Emissions

The value of $\bar{\chi}_{max}$ may be derived from χ_{max}, an undefined "short-term" concentration. An approximation for longer term concentration may be made as follows (35):

For a 24-hr time period,

$$\bar{\chi}_{max} = \chi_{max}\left(\frac{t_o}{t}\right)^{0.17} \qquad \text{(B-23)}$$

or

$$\bar{\chi}_{max} = \chi_{max}\left(\frac{3\ \text{min}}{1{,}440\ \text{min}}\right)^{0.17} \qquad \text{(B-24)}$$

$$\bar{\chi}_{max} = \chi_{max}\ (0.35) \qquad \text{(B-25)}$$

Since the hazard factor is defined and derived from TLV values as follows:

$$F = (\text{TLV})\left(\frac{8}{24}\right)\left(\frac{1}{100}\right) \qquad \text{(B-26)}$$

$$F = (3.33 \times 10^{-3})\ \text{TLV} \qquad \text{(B-27)}$$

then the severity factor, S, is defined as

$$S = \frac{\bar{\chi}_{max}}{F} = \frac{0.35\ \chi_{max}}{(3.33 \times 10^{-3})\ \text{TLV}} \qquad \text{(B-28)}$$

$$S = \frac{105\ \chi_{max}}{TLV} \qquad (B-29)$$

If a weekly averaging period is used, then

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{3}{10{,}080}\right)^{0.17} \qquad (B-30)$$

or

$$\bar{\chi}_{max} = 0.25\ \chi_{max} \qquad (B-31)$$

and

$$F = (TLV)\left(\frac{40}{168}\right)\left(\frac{1}{100}\right) \qquad (B-32)$$

$$F = (2.38 \times 10^{-3})TLV \qquad (B-33)$$

and the severity factor, S, is

$$S = \frac{\bar{\chi}_{max}}{F} = \frac{0.25\ \chi_{max}}{(2.38 \times 10^{-3})TLV} \qquad (B-34)$$

or

$$S = \frac{105\ \chi_{max}}{TLV} \qquad (B-35)$$

which is entirely consistent, since the TLV is being corrected for a different exposure period.

Therefore, the severity can be derived from χ_{max} directly without regard to averaging time for noncriteria emissions. Thus, combining Equations B-35 and B-21, for elevated sources, gives

$$S = \frac{5.5\ Q}{TLV \cdot H^2} \qquad (B-36)$$

Criteria Emissions

For the criteria pollutants, established standards may be used as F values in Equation B-22. These are given in Table B-4 (50).

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(50) Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 pp.

However, Equation B-23 must be used to give the appropriate averaging period. These equations are developed for elevated sources using Equation B-21.

TABLE B-4. SUMMARY OF NATIONAL AMBIENT AIR QUALITY STANDARDS (50)

Pollutant	Averaging time	Primary standards, $\mu g/m^3$	Secondary standards, $\mu g/m^3$
Particulate matter	Annual (geometric mean)	75	60[a]
	24-hr[b]	260	160
SO_x	Annual (arithmetic mean)	80	60
	24-hr[b]	365	260[c]
	3-hr[b]	-[d]	1,300
CO	8-hr[b]	10,000	10,000
	1-hr[b]	40,000	40,000
Nitrogen dioxide	Annual (arithmetic mean)	100	100
Photochemical oxidants	1-hr[b]	160	160
Hydrocarbons (nonmethane)	3-hr (6 a.m. to 9 a.m.)	160[e]	160

[a] The secondary annual standard (60 $\mu g/m^3$) is a guide for assessing implementation plans to achieve the 24-hr secondary standard.

[b] Not to be exceeded more than once per year.

[c] No standard exists.

[d] The secondary annual standard (260 $\mu g/m^3$) is a guide for assessing implementation plans to achieve the annual standard.

[e] There is no primary ambient air quality standard for hydrocarbons. The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is an EPA-recommended guideline for meeting the primary ambient air quality standard for oxidants.

Carbon Monoxide Severity--

The primary standard for CO is reported for a 1-hr averaging time. Therefore

$$t = 60 \text{ min}$$

$$t_o = 3 \text{ min}$$

$$\overline{\chi}_{max} = \chi_{max}\left(\frac{3}{60}\right)^{0.17} \qquad \text{(B-37)}$$

$$= \frac{2\ Q}{\pi e u H^2}\left(\frac{3}{60}\right)^{0.17} \qquad \text{(B-38)}$$

$$= \frac{2\ Q}{(3.14)(2.72)(4.5)H^2}\ 0.6 \qquad \text{(B-39)}$$

$$\overline{\chi}_{max} = \frac{0.052\ Q}{H^2}\ 0.6 \qquad \text{(B-40)}$$

$$\overline{\chi}_{max} = \frac{(3.12 \times 10^{-2})Q}{H^2} \qquad \text{(B-41)}$$

$$\text{Severity, } S = \frac{\overline{\chi}_{max}}{F} \quad \text{(B-42)}$$

Setting F equal to the primary standard for CO; i.e., 0.04 g/m^3, yields

$$S = \frac{\overline{\chi}_{max}}{F} = \frac{(3.12 \times 10^{-2})Q}{0.04\ H^2} \quad \text{(B-43)}$$

or

$$S_{CO} = \frac{0.78\ Q}{H^2} \quad \text{(B-44)}$$

Hydrocarbon Severity--
The primary standard for hydrocarbon is reported for a 3-hr averaging time.

$$t = 180 \text{ min}$$

$$t_o = 3 \text{ min}$$

$$\overline{\chi}_{max} = \chi_{max} \left(\frac{3}{180}\right)^{0.17} \quad \text{(B-45)}$$

$$= 0.5\chi_{max} \quad \text{(B-46)}$$

$$= \frac{(0.5)(0.052)Q}{H^2} \quad \text{(B-47)}$$

$$\overline{\chi}_{max} = \frac{0.026\ Q}{H^2} \quad \text{(B-48)}$$

For hydrocarbons, the concentration of 1.6 x 10^{-4} g/m^3 has been issued as a guideline for achieving oxidant standards. Therefore,

$$S = \frac{\overline{\chi}_{max}}{F} = \frac{0.026\ Q}{1.6 \times 10^{-4}\ H^2} \quad \text{(B-49)}$$

or

$$S_{HC} = \frac{162.5\ Q}{H^2} \quad \text{(B-50)}$$

Particulate Severity--
The primary standard for particulate is reported for a 24-hr averaging time.

$$\overline{\chi}_{max} = \chi_{max}\left(\frac{3}{1,440}\right)^{0.17} \quad (B\text{-}51)$$

$$= \frac{(0.05)(0.052)Q}{H^2} \quad (B\text{-}52)$$

$$\overline{\chi}_{max} = \frac{0.0182\ Q}{H^2} \quad (B\text{-}53)$$

For particulates, $F = 2.6 \times 10^{-4}$ g/m³, and

$$S = \frac{\overline{\chi}_{max}}{F} = \frac{0.0182\ Q}{(2.6 \times 10^{-4})H^2} \quad (B\text{-}54)$$

$$S_P = \frac{70\ Q}{H^2} \quad (B\text{-}55)$$

SO_x Severity--
The primary standard for SO_x is reported for a 24-hr averaging time.

$$\overline{\chi}_{max} = \frac{0.0182\ Q}{H^2} \quad (B\text{-}56)$$

The primary standard is 3.65×10^{-4} g/m³. Therefore,

$$S = \frac{\overline{\chi}_{max}}{F} = \frac{0.0182\ Q}{(3.65 \times 10^{-4})H^2} \quad (B\text{-}57)$$

or

$$S_{SO_x} = \frac{50\ Q}{H^2} \quad (B\text{-}58)$$

NO_x Severity--
Since NO_x has a primary standard with a 1-yr averaging time, the χ_{max} correction equation cannot be used. As an alternative, the following equation is used:

$$\overline{\chi} = \frac{2.03\ Q}{\sigma_z u x} \exp -\left[\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad (B\text{-}59)$$

A difficulty arises, however, because a distance x, from emission point to receptor, is included; hence, the following rationale is used:

$$\chi_{max} = \frac{2\ Q}{\pi e u H^2}$$

is valid for neutral conditions or when σ_z equals σ_y. This maximum occurs when

$$H = \sqrt{2}\sigma_z$$

and since, under these conditions,

$$\sigma_z = ax^b$$

then the distance, x_{max}, where the maximum concentration occurs is

$$x_{max} = \left(\frac{H}{\sqrt{2a}}\right)^{\frac{1}{b}}$$

For class C conditions,

$$a = 0.113$$

$$b = 0.911$$

Simplifying Equation B-59,

$$\sigma_z = 0.113\ x_{max}{}^{0.911}$$

and

$$u = 4.5 \text{ m/s}$$

Letting $x = x_{max}$ in Equation B-59,

$$\overline{\chi}_{max} = \frac{4\ Q}{x_{max}{}^{1.911}} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{(B-60)}$$

where

$$x_{max} = \left(\frac{H}{0.16}\right)^{1.098} \qquad \text{(B-61)}$$

$$x_{max} = 7.5\ H^{1.098} \qquad \text{(B-62)}$$

and

$$\frac{4\ Q}{x_{max}{}^{1.911}} = \frac{4\ Q}{(7.5\ H^{1.098})^{1.911}} \qquad \text{(B-63)}$$

Therefore,

$$\overline{\chi}_{max} = \frac{0.085\ Q}{H^{2.1}} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \tag{B-64}$$

As noted above,

$$\sigma_z = 0.113\ x^{0.911} \tag{B-65}$$

$$\sigma_z = 0.113(7.5\ H^{1.1})^{0.911} \tag{B-66}$$

or

$$\sigma_z = 0.71\ H \tag{B-67}$$

Therefore,

$$\overline{\chi}_{max} = \frac{0.085\ Q}{H^{2.1}} \exp\left[-\frac{1}{2}\left(\frac{H}{0.71\ H}\right)^2\right] \tag{B-68}$$

$$= \frac{0.085\ Q}{H^{2.1}}\ (0.371) \tag{B-69}$$

$$\overline{\chi}_{max} = \frac{3.15 \times 10^{-2}\ Q}{H^{2.1}} \tag{B-70}$$

Since the NO_x standard is 1.0×10^{-4} g/m³, the NO_x severity equation is

$$S_{NO_x} = \frac{(3.15 \times 10^{-2})Q}{1 \times 10^{-4}\ H^{2.1}} \tag{B-71}$$

$$S_{NO_x} = \frac{315\ Q}{H^{2.1}} \tag{B-72}$$

APPENDIX C

EXAMPLES OF SOURCE SEVERITY CALCULATIONS

Uncontrolled Emission Factor

Particulate

28 g/kg to 406 g/kg charcoal produced

Annual Uncontrolled Emission Rate

Batch Kiln

$$196.61\ \frac{\text{metric ton}}{\text{yr}} \times \frac{10^3\ \text{kg}}{\text{metric ton}} \times (28\ \text{g/kg to } 406\ \text{g/kg})$$

$$= 5.51 \times 10^6 \text{ to } 7.98 \times 10^7\ \text{g/yr}$$

Continuous furnace

$$20{,}300\ \frac{\text{metric ton}}{\text{yr}} \times \frac{10^3\ \text{kg}}{\text{metric ton}} \times (28\ \text{g/kg to } 406\ \text{g/kg})$$

$$= 5.68 \times 10^8 \text{ to } 8.24 \times 10^9\ \text{g/yr}$$

Average Uncontrolled Emission Rate

Batch Kiln

Although the emissions are cyclic, assume they are constant over the period of emission. Assume 15.88 metric tons of charcoal are produced per cycle, and each cycle emits for 10 days of the cycle.

Annual period of emission =

$$196.61\ \frac{\text{metric ton}}{\text{yr}} \times \frac{\text{cycle}}{15.88\ \text{metric ton}} \times \frac{10\ \text{days emission}}{\text{cycle}}$$

$$\times \frac{8.64 \times 10^4\ \text{s}}{\text{day}} = 1.07 \times 10^7\ \text{s/yr}$$

Average uncontrolled emission rate =

$$\frac{5.51 \times 10^{6}\ \text{g/yr to } 7.98 \times 10^{7}\ \text{g/yr}}{1.07 \times 10^{7}\ \text{s/yr}} = 0.51\ \text{g/s to } 7.46\ \text{g/s}$$

Continuous furnace

Annual period of emission 8,000 hr/yr

Average uncontrolled emission rate:

$$\frac{5.68 \times 10^{8}\ \text{g/yr to } 8.24 \times 10^{9}\ \text{g/yr}}{8{,}000\ \text{hr/yr} \times 3{,}600\ \text{s/hr}} = 19.7\ \text{g/s to } 286\ \text{g/s}$$

Uncontrolled Time-Averaged Maximum Ground Level Concentration, $\overline{\chi}_{max}$

$$\overline{\chi}_{max} = \frac{2\,Q}{\pi e \bar{u} h^{2}} \left(\frac{t_o}{t}\right)^{0.17}$$

where
Q = emission rate, g/s
e = 2.72
$\bar{u}$ = national average wind speed, 4.5 m/s
h = stack height, m
t_o = short-term averaging time, 3 min
t = 1,440 min

$$\overline{\chi}_{max} = 1.82 \times 10^{-2}\ \frac{Q}{h^{2}}$$

Batch Kiln

$Q = 0.51$ g/s to 7.46 g/s

$h = 4.57$ m (assumed)

$\overline{\chi}_{max} = 4.44 \times 10^{-4}\ \text{g/m}^3$ to $6.50 \times 10^{-3}\ \text{g/m}^3$

Continuous Furnace

$Q = 19.7$ g/s to 286 g/s
$h = 21.34$ m (assumed)
$\overline{\chi}_{max} = 7.87 \times 10^{-4}\ \text{g/m}^3$ to $1.14 \times 10^{-2}\ \text{g/m}^3$

Uncontrolled Source Severity

$$S = \frac{\overline{\chi}_{max}}{F}$$

where F for particulate is the ambient air quality standard, 2.6×10^{-4} g/m^3

Batch Kiln

$$S = \frac{4.44 \times 10^{-4}\ g/m^3 \text{ to } 6.50 \times 10^{-3}\ g/m^3}{2.6 \times 10^{-4}\ g/m^3} = 1.71 \text{ to } 25$$

Continuous Furnace

$$\frac{7.87 \times 10^{-4}\ g/m^3 \text{ to } 1.14 \times 10^{-2}\ g/m^3}{2.6 \times 10^{-4}\ g/m^3} = 3.03 \text{ to } 44.0$$

APPENDIX D[a]

EMISSION FACTOR COMPILATION

The uncontrolled emission factors used to characterize charcoal emissions are summarized in Table D-1. The following discussion presents raw data input and procedures used to generate the emission factors shown.

TABLE D-1. UNCONTROLLED EMISSION FACTORS FOR CHARCOAL MANUFACTURE (g/kg)

Emission species	Charcoal manufacture	Briquetting
Particulate	28 to 406	7 to 42
Carbon monoxide	160 to 179	-[a]
Methanol	67 to 76	-[a]
Acetic acid	102 to 116	-[a]
Methane	44 to 57	-[a]
Hydrogen	0.5 to 2	-[a]
Polycyclic organic materials	0.004	-[a]
Nitrogen oxides	12	-[a]
Other gases[b]	7 to 60	-[a]

[a] No information available.

[b] Other gases are defined to include higher hydrocarbons (non-methane noncondensibles), ethane, unsaturated hydrocarbons, and formaldehyde.

DERIVATION OF TABLE 5 COMPOSITION RANGE FOR NONCONDENSIBLE PRODUCTS OF CHARCOAL MANUFACTURE

Table 5 was compiled using input from References 3, 16 and 17. Table D-2 presents a compilation of the input material from each reference.

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[a] Nonmetric units are used in this appendix because they are the type that were utilized in performing the calculations described. All results in the report proper are shown in metric units.

TABLE D-2. INPUT DATA FOR GENERATION OF TABLE 5

	Reference no.:	3	16	17	
	Reference page no.:	405	478	50	
Compounds	Units:	Volume %	Volume %	Pounds	(Volume %)
Carbon dioxide		50.74	50 to 60	523	(53)
Carbon monoxide		27.88	28 to 33	172	(27)
Methane		11.36	3.5 to 18	55	(15)
Hydrogen		4.21	1 to 3		
Higher hydrocarbons[a]			1 to 3		
Ethane		3.09		30	(5)
Unsaturated hydrocarbons; e.g., ethylene		2.72			

[a] Higher hydrocarbons are not defined by Reference 16 but are assumed to be nonmethane noncondensible hydrocarbons.

Note.—Blanks indicate information not available.

The masses from Reference 17 were converted to volume percent as shown in Table D-3 (assuming ideal gas behavior).

TABLE D-3. CONVERSION OF MASS TO VOLUME PERCENT

Compound	Pounds	Molecular weight	Moles	Volume %
Carbon dioxide	523	44	11.9	53
Carbon monoxide	172	28	6.1	27
Methane	55	16	3.4	15
Ethane	30	30	1.0	5
TOTAL	780		22.4	100

A summary of the ranges of composition and an assumed average composition for all the references appears in Table D-4.

TABLE D-4. COMPOSITION RANGE AND ASSUMED AVERAGE COMPOSITION FOR NONCONDENSIBLE PRODUCTS OF CHARCOAL MANUFACTURE

	Percent of noncondensibles	
Compound	Range	Assumed average
Carbon dioxide	50 to 60	55
Carbon monoxide	27 to 33	30
Methane	3 to 18	9
Hydrogen	1 to 4	2.5
Higher hydrocarbons[a]	1 to 6	3.5

[a] Higher hydrocarbons are assumed to be nonmethane noncondensible hydrocarbons; i.e., ethane and unsaturated hydrocarbons are combined to give a total higher hydrocarbon value.

DERIVATION OF TABLE 8, RANGE OF EMISSION FACTORS FOR CHARCOAL MANUFACTURE

Table 8 was compiled using References 17, 19, 27, and 30-32 plus references to Table 5, presented previously. Table D-5 presents a compilation of the input material from each reference.

TABLE D-5. INPUT DATA FOR GENERATION OF TABLE 8

Emission[a]	Reference: Reference page no.: Operation: Type of emission factor: Units:	17 50 Charcoal Uncontrolled Pounds	19 6, 10 Charcoal Uncontrolled See below	27 306 Charcoal Uncontrolled 10^6 lb/yr	30 5.4.1 Charcoal Uncontrolled kg/MT	31 6 Charcoal Uncontrolled lb/hr	32 18, 87 Briquetting Controlled tons/yr
Tar		200					
Pyroacids		190					
Carbon monoxide		172			160		
Methane		55					
Particulate			126.4 to 160.5 lb/ton[b]			4.23	20, 17
Polycyclic organic material							
Combustible particulate				193			
Hydrocarbon				48	50		
Methanol				73			
Acetic acid				112	116		
Particulate (tar, oil)					200		
Crude methanol					76		

[a] An additional controlled particulate emission factor of 1.25×10^{-3} lb particulate/lb briquet was obtained from an industry survey.

[b] Daily emission rates over a 6-day period were $1,122.4 \times 10^{-6}$ lb/yr, 691.8×10^{-6} lb/hr, 309.2×10^{-6} lb/hr, 613.2×10^{-6} lb/hr, $1,067.8 \times 10^{-6}$ lb/hr, and $2,278.7 \times 10^{-6}$ lb/hr.

Note.—Blanks indicate no information available.

Additional information required to convert the data in Table D-5 into uncontrolled emission factors (g/kg) was obtained from the appropriate references. The charcoal yield of 960 pounds (17) was required. The duration of a production cycle, 6 days (19), and the batch production rate, 18 tons/cycle (19) were required. The annual production rate of 548,000 tons (27) was required. The duration of the cycle, 21 days, and the batch size, 18 tons of charcoal (31), were required. Other necessary information included charcoal production rates and control efficiencies, 8,100 tons/yr and 40,300 tons/yr and 65% and 99%, respectively (32). Several assumptions were made. Tar, pyroacids, particulate, combustible particulate, and particulate (tar, oil) were assumed to be synonymous. Likewise, methane and hydrocarbon were assumed to be the same as were methanol and crude methanol. Emission factors are presented in Table D-6.

Emission factors for other noncondensible gases were generated using the input information presented in Table D-7.

These data were combined to generate three emission factors; i.e., nitrogen oxides, hydrogen, and other gases (defined as nonmethane noncondensible hydrocarbons; i.e., higher hydrocarbons, ethane, unsaturated hydrocarbons, and formaldehyde).

TABLE D-6. UNCONTROLLED EMISSION FACTORS DERIVED FROM TABLE D-5 (g/kg)

	Reference					
Emission	17[a]	19[b]	27[c]	30[d]	31[e]	32[f]
Particulate[g]	406	63 to 80	176	200	59	7 to 42
Carbon monoxide	179			160		
Methanol			67	76		
Acetic acid			102	116		
Methane	57		44	50		
Polycyclic organic materials		0.004				

Note.—Blanks indicate no information available.

[a]

Particulate: $\frac{200\text{ lb} + 190\text{ lb}}{960\text{ lb charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 406\text{ g/kg}$

Carbon monoxide: $\frac{172\text{ lb}}{960\text{ lb charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 179\text{ g/kg}$

Methane: $\frac{55\text{ lb}}{960\text{ lb charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 57\text{ g/kg}$

[b]

Particulate: $\frac{126.4\text{ lb to }160.5\text{ lb}}{\text{ton charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 63\text{ g/kg to }80\text{ g/kg}$

Polycyclic organic material:

Average daily emission = Day 1 + Day 2 + Day 3 + Day 4 + Day 5 + Day 6

$$\frac{(1{,}122.4 + 691.8 + 309.2 + 613.2 + 1{,}062.8 + 2{,}278.7) \times 10^{-6}\text{ lb/hr (24-hr/day)}}{18\text{ ton}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 4.0 \times 10^{-3}\text{ g/kg}$$

[c]

Particulate: $\frac{193 \times 10^6\text{ lb/yr}}{548{,}000\text{ ton/yr charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 176\text{ g/kg}$

Methane: $\frac{48 \times 10^6\text{ lb/yr}}{548{,}000\text{ ton/yr charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 44\text{ g/kg}$

Methanol: $\frac{73 \times 10^6\text{ lb/yr}}{548{,}000\text{ ton/yr charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 67\text{ g/kg}$

Acetic acid: $\frac{112 \times 10^6\text{ lb/yr}}{548{,}000\text{ ton/yr charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 102\text{ g/kg}$

[d]

All emissions: emission factor $\frac{\text{kg}}{\text{MT}}\left(\frac{10^3\text{ g}}{\text{kg}}\right)\left(\frac{\text{MT}}{10^3\text{ kg}}\right)$ = emission factor

[e]

Particulate: $\frac{4.23\text{ lb/hr (24 hr/day)(21 day)}}{18\text{ ton charcoal}}\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 59\text{ g/kg}$

[f]

Particulate: $\frac{20\text{ ton/yr controlled}}{8{,}100\text{ ton/yr charcoal}}\left(\frac{2{,}000\text{ lb}}{\text{ton}}\right)\left(\frac{100\text{ lb uncontrolled}}{35\text{ lb controlled}}\right)\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 7\text{ g/kg}$

$\frac{17\text{ ton/yr controlled}}{40{,}300\text{ ton/yr charcoal}}\left(\frac{2{,}000\text{ lb}}{\text{ton}}\right)\left(\frac{100\text{ lb uncontrolled}}{1\text{ lb controlled}}\right)\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 42\text{ g/kg}$

[g] The industrial survey controlled particulate emission factor of 1.25×10^{-3} lb particulate/lb briquet was converted to an uncontrolled emission factor assuming 95% control efficiency and a briquet containing 90% charcoal as follows:

$$1.25 \times 10^{-3}\ \frac{\text{lb particulate controlled}}{\text{lb briquet}}\left(\frac{\text{lb briquet}}{0.9\text{ lb charcoal}}\right)\left(\frac{2{,}000\text{ lb}}{\text{ton}}\right)\left(\frac{20\text{ lb uncontrolled}}{\text{lb controlled}}\right)\left(\frac{454\text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{2.2\text{ lb}}{\text{kg}}\right) = 28\text{ g/kg}$$

TABLE D-7. INPUT DATA FOR GENERATION OF UNCONTROLLED EMISSION FACTORS FOR OTHER NONCONDENSIBLE GASES

Compound	Reference:	3	16	17		30
	Reference page no.:	405	478	50		5.4.1
	Units:	Volume %	Volume %	Pounds	Volume %	kg/MT
Hydrogen		4.21	1 to 3			
Higher hydrocarbon[a]			1 to 3			
Ethane		3.09		30	5	
Unsaturaged hydrocarbons, e.g., ethylene		2.72				
Other gases (HCHO, N_2, NO)						30

[a] Higher hydrocarbons are not defined by Reference 16 but are assumed to be nonmethane noncondensible hydrocarbons.

Note.—Blanks indicate no information available.

Both controlled and uncontrolled nitrogen oxide emission factors were estimated using engineering calculations. The uncontrolled emission factor for nitrogen oxides was calculated assuming that no oxides of nitrogen were formed by thermal fixation of air and that all fuel nitrogen was oxidized to NO. Thermal fixation of air is excluded since the normal operating temperatures of charcoal manufacture (approximately 500°C) are not high enough to promote NO formation, as suggested by Table D-8 (34).

TABLE D-8. TIME FOR NO FORMATION IN A GAS CONTAINING 75% NITROGEN AND 3% OXYGEN (34)

Temperature, °C	Time to form 500 ppm NO, s	NO concentration at equilibrium, ppm
1,360	1,370	550
1,538	16.2	1,380
1,760	1.10	2,600
1,982	0.117	4,150

Nitrogen oxides formed from wood nitrogen were calculated assuming all of the 0.14% nitrogen in wood was oxidized to NO. The wood nitrogen content is the average for four woods identified on page 160 of Reference 33. With the assumption that 4 kg of wood are needed to produce 1 kg of charcoal (23), the uncontrolled emission factor is derived as follows:

$$\frac{0.14 \text{ g N}}{100 \text{ g wood}} \left(\frac{30 \text{ g NO}}{14 \text{ g N}}\right)\left(\frac{4{,}000 \text{ g wood}}{\text{kg charcoal}}\right) = 12 \text{ g/kg}$$

Control of combustible emissions by afterburning generates nitrogen oxides. Page 24 of Reference 27 gives an emission factor of 0.05 to 0.1 lb NO_x/MM Btu fuel, and an average value of 0.075 was chosen for calculations. The heating value of combustible gases is estimated to be 25 MM Btu/ton charcoal (26). Therefore, nitrogen oxides generated by afterburning are:

$$0.075 \frac{\text{lb } NO_x}{\text{MM Btu fuel}} \left(25 \frac{\text{MM Btu}}{\text{ton charcoal}}\right)\left(\frac{454 \text{ g}}{\text{lb}}\right)\left(\frac{\text{ton}}{2{,}000 \text{ lb}}\right)\left(\frac{2.2 \text{ lb}}{\text{kg}}\right) = 0.94 \text{ g/kg}$$

The controlled emission factor is the sum of the uncontrolled emissions plus those generated by control.

$$12 \text{ g/kg} + 0.94 \text{ g/kg} = \sim 13 \text{ g/kg}$$

Estimates of hydrogen emissions range from 1% to 4.21% of noncondensibles. To convert this to a mass emission and an emission factor, the required molecular weight for the noncondensibles is calculated from the average noncondensible composition in Table D-4 as follows:

$$\underset{CO_2}{0.55(44)} + \underset{CO}{0.3(28)} + \underset{CH_4}{0.09(16)} + \underset{H_2}{0.025(2)} + \underset{\text{Higher hydrocarbon}(C_2H_6)}{0.035(30)} = 35.1$$

Also required is a noncondensibles emission factor; i.e., g noncondensibles/g charcoal. From Reference 15, this number is 25 g noncondensibles/31 g charcoal. A hydrogen emission factor can then be calculated.

$$\frac{\text{1 mole to 4.21 moles hydrogen}}{\text{100 moles noncondensibles}} \left(\frac{\text{2 g hydrogen}}{\text{mole hydrogen}}\right)\left(\frac{\text{mole noncondensible}}{\text{35.1 g noncondensible}}\right)\left(\frac{\text{2,500 g noncondensibles}}{\text{31 kg charcoal}}\right) = 0.5 \text{ g/kg to 2 g/kg}$$

Only an emission factor for the other gases (higher hydrocarbons, ethane, unsaturated hydrocarbons, and formaldehyde) remains to be calculated. The relationship between these other gases as well as the input available on each from Table D-7 follows.

Other gases = higher hydrocarbons (formaldehyde + ethane + unsaturated hydrocarbons)
1% to 3% noncondensibles (18 g/kg + 30 lb to 3.09% noncondensibles + 2.72% noncondensibles)

Higher hydrocarbons are converted to an emission factor as follows:

$$\frac{\text{1 mole to 3 moles higher hydrocarbon}}{\text{100 moles noncondensibles}} \left(\frac{\text{30 g higher hydrocarbon } (C_2H_6)}{\text{mole higher hydrocarbon}}\right)\left(\frac{\text{mole noncondensible}}{\text{35.1 g noncondensible}}\right)\left(\frac{\text{25,000 g noncondensibles}}{\text{31 kg charcoal}}\right) = 7 \text{ to 21 g/kg}$$

The formaldehyde emission factor is merely other gases (formaldehyde, nitrogen, nitric oxide) minus the nitrogen oxide emission factor, 12 g/kg, calculated above. Ethane emission factors are

$$\frac{3.09\ \text{moles ethane}}{100\ \text{moles noncondensibles}}\left(\frac{30\ \text{g ethane}}{\text{mole higher hydrocarbon}}\right)\left(\frac{\text{mole noncondensible}}{35.1\ \text{g noncondensible}}\right)\left(\frac{25{,}000\ \text{g noncondensible}}{31\ \text{kg charcoal}}\right) = 21\ \text{g/kg}$$

or

$$\frac{30\ \text{lb ethane}}{960\ \text{lb charcoal}}\left(\frac{454\ \text{g}}{\text{lb}}\right)\left(\frac{\text{lb}}{454\ \text{g}}\right)\left(\frac{1{,}000\ \text{g}}{\text{kg}}\right) = 31\ \text{g/kg}$$

The unsaturated hydrocarbon emission factor is calculated assuming they are ethylene

$$\frac{2.72\ \text{moles unsaturated hydrocarbon}}{100\ \text{moles noncondensibles}}\left(\frac{28\ \text{g unsaturated hydrocarbons}}{\text{mole unsaturated hydrocarbon}}\right)\left(\frac{\text{mole noncondensible}}{35.1\ \text{g noncondensible}}\right)\left(\frac{25{,}000\ \text{g noncondensible}}{31\ \text{kg charcoal}}\right) = 17\ \text{g/kg}$$

An emission factor for other gases can be calculated as below.

Other gases = higher hydrocarbon (formaldehyde + ethane + unsaturated hydrocarbons)
7 g/kg to 21 g/kg (12 g/kg + 21 g/kg to 31 g/kg + 17 g/kg)

Therefore, other gases range from 7 g/kg to 60 g/kg.

APPENDIX E

INDUSTRY COMMENT TO SOURCE ASSESSMENT: CHARCOAL MANUFACTURING, STATE OF THE ART

The Charcoal Briquet Institute of Oak Brook, Illinois expressed the desire to add a listing of industrial comments to this report. The following are their comments (November 1977).

FOREWARD

The Charcoal Briquet Institute, trade association for charcoal briquet manufacturers in the United States, is pleased to submit this review and evaluation of a report recently completed by Monsanto Research Corporation identified as Contract No. 6802-1874, SOURCE ASSESSMENT: CHARCOAL MANUFACTURING, State of the Art.

Numerous changes and improvements have been included in the reviewed MRC document published under the date of November 1977. Likewise, it must be emphasized that much expert opinion provided by industry authorities was not included in the final MRC report.

This Appendix has been prepared by the Charcoal Briquet Institute for the purpose of providing additional background information that will improve the total report being developed by Monsanto Research Corporation.

The Institute, in this review and evaluation of the "SOURCE ASSESSMENT: CHARCOAL MANUFACTURING, State of the Art" report, has assumed an objective position of evaluating overall report results and the quality of statements and data therein.

The Charcoal Briquet Institute is organized under the General Not For Profit Corporation Act of the State of Illinois and engages in a number of lawful activities which promote the interests of the charcoal briquet manufacturing industry and the public in general.

Since original organization in 1958, the Institute has maintained an acute awareness of its responsibility to public and private agencies interested in the charcoal manufacturing industry. Therefore, the Institute has willingly and continually maintained close liaison with representatives of the Monsanto Research Corporation as this industry study developed the past two years.

SUMMARY OF RECOMMENDATIONS

The report is identified as a SOURCE ASSESSMENT of charcoal manufacturing. It is the Institute's position that the report is not an "assessment" since no field sampling was completed by Monsanto Research Corporation and no contemporary facts based upon reliable data or engineering studies were available to include in the report.

Therefore, the Institute also recommends that the words, "SOURCE ASSESSMENT," be deleted in all cases and that the report be identified as a "State of the Art" document in accordance with established protocol.

Substantiation of Recommendations

The Charcoal Briquet Institute has submitted these previous recommendations for the following reasons:

- General availability of this report would be a disservice to the public in general who depend upon public and private agencies for the generation of reliable knowledge and facts related to complex public issues.
- The report could also severely damage the charcoal briquet manufacturing industry that produces products now utilized by an estimated 166,000,000 people annually.
- Many of the companies are small businesses and are not in a position to cope with the increasing regulatory impact from matters associated with environment, transportation and product liability.
- Special interest groups and well-meaning citizens who use this document for resource data may not be aware of or understand the complex assumptions and equations that went into the final report.
- Emission factors as presented in the report are key inputs to the study. MRC obtained none of the data from actual measurements, but instead relied on literature estimates.
- No meaningful discussion of the development of uncontrolled emission factors is provided. These uncontrolled emission factors are probably the single most important figures in the report.
- Production estimates in the states are not based on accurate data.

- The composition of finished charcoal briquet production and potential effect on emissions is inaccurate and should not be used in the report.

- The report confuses the overall emissions situation by presenting summary data that are inaccurate and incomplete.

- The treatment of incineration and source severity lacks sufficient technical detail for proper evaluation of pollution characteristics of the charcoal briquet industry.

- A more careful consideration of the true nature of the particulate emissions from charcoal plants would result in much less severe environmental impact estimates.

- The data that are used to develop the final estimates are obsolete in many cases and incorrect and without basis in other cases.

CHARCOAL MANUFACTURING: THE POSITIVE CONTRIBUTIONS TO AMERICA

A high percent of all charcoal manufactured in the United States is processed into charcoal briquets for use as a cooking fuel in charcoal barbecue grills.

The industry is an important energy producer and an estimated 645,000,000 charcoal barbecues in 1977 replaced a vast amount of cooking energy that would have been drawn from the nation's electrical power generating network or natural gas supplies.

As the industry developed during the past two-and-one-half decades, it has become a major user of wood wastes from the nation's forest products industry.

Forest products wastes that are now gathered and manufactured into charcoal briquets have reduced emissions from incineration of wastes at hundreds of plant sites throughout the U.S.

Pollution control technology available to the industry is now in use at charcoal briquetting plants and the trend toward continous processing of charcoal has allowed the industry to effectively control emissions in compliance with state and federal regulations at these manufacturing locations.

Charcoal briquet manufacturers provide a unique and vital service to America. Industry products make significant contributions to the nation's energy supply. Concurrently, the charcoal manufacturing industry has contributed to a massive reduction in total emissions formerly generated by forestry management practices and the elimination of unwanted byproducts from the nation's forest products industries.

COMMENTS AND OBSERVATIONS

The Charcoal Briquet Institute hereby presents these comments and observations regarding this final report.

Cover Page

The Institute recommends that SOURCE ASSESSMENT be deleted from the cover page since the report will be more accurately identified as a "State of the Art" document or a "General Background Report" about the charcoal manufacturing industry.

Disclaimer (Page ii)

On line three following the word "Approval," the Institute recommends that "for publication" be added.

Because of the sequential prominence of this page, it is also recommended that this copy be added to the Disclaimer page:

> "The U.S. Environmental Protection Agency is aware that no samples were taken of any charcoal manufacturing operations by Monsanto Research Corporation to determine actual emissions and that technical data set forth in this document is based upon suppositions and purely hypothetical estimates. *(See definition of State-of-the-Art Report, Page v - Ed.)*
>
> "In addition, scientifically reliable data on the total emissions from all industrial sources in the states are not presently known. Therefore, comparative data on charcoal manufacturing as a percent of the total should not be presumed as an accurate representation." *(Total emissions from all sources are referenced, Page 34, Reference 36 - Ed.)*

Preface (Page iv)

In paragraph two of the Preface, it is stated,

> "This is a determination which should not be made on superficial information; consequently, each of the industries is being evaluated in detail to determine if there is, in EPA's judgment, sufficient environmental risk associated with the process to invest in the development of control technology."

It is the Institute's position that this document has presented information based on suppositions and estimates, and that the basic objective of providing reliable data <u>has not been achieved</u>.

The first sentence of the fourth paragraph on Page iv states that:

> "Source Assessment Documents contain data on emissions from specific industries."

This statement further substantiates the Institute's position that the report should not be identified as a "Source Assessment" document.

This same paragraph goes on to state:

> "Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source emissions."

This statement further substantiates the Institute's position that the document cannot be considered a factual assembly of industry data when no sampling and analysis were undertaken.

Abstract (Page vi)

The Institute recommends that data set forth in paragraph three not be considered as an accurate representation since no sampling has been completed to determine relationships with total national emissions or ground level concentrations which are indicated at 0.1% and 1.0%, respectively.

The report presents estimates of the maximum possible emission levels. Actual emission levels are considerably lower than the maximum estimates. Maximum estimates provide no basis for the evaluation of emissions by the charcoal briquet industry.

Summary (Page 2)

The word "examines" in the second sentence of the first paragraph should more appropriately be "relates to" or similar language since "examines" implies careful inquiry, testing, or investigative scrutiny.

Paragraph two indicates that charcoal manufacture represents an estimated 1,330 batch kilns and 16 continuous furnaces. The Charcoal Briquet Institute estimates that there are approximately 750 to 1,000 batch kilns now operating in the United States. It has also been well established that the percent of finished briquet production originating in charcoal kilns is less than 45% of the total U.S. production.

The final sentence in paragraph two states:

> "Missouri produces an estimated 45% of national production."

No accurate records exist regarding the percentage of production originating in the State of Missouri. Data generated by the Charcoal Briquet Institute reveals that carbonaceous materials subjected to pyrolysis in Missouri and added to the charcoal briquet product mix contributes approximately 16% of total national finished charcoal briquet tonnage produced.

Table 2, Page 3

Industry authorities who are aware of charcoal manufacture in the various states, and the total amount of industrial activity, believe it is inconceivable that charcoal generates 1% of particulate matter, carbon monoxide, or nitrogen oxide in the states noted.

The table neglects the fact that the report only produces maximum estimates, not actual emissions. There is no technical basis behind the conclusions in this table. Indeed, this entire table provides information that is beyond the scope of facts available.

Table 1, Page 3

The Charcoal Briquet Institute believes that all data set forth in Table 1 is suspect because sampling of the industry was not conducted. Suppositions set forth in Table 1 are based upon estimates which the Monsanto Research Corporation labeled:

> "Of questionable utility due to the improvisational sampling techniques utilized."

Uncontrolled emissions are discussed on this page and at other locations in this report. Uncontrolled continuous emissions do not exist because all continuous sources are controlled. Any discussion of uncontrolled continuous emissions is irrelevant and confusing, and, therefore, detracts from the purpose of performing the study.

Paragraphs 2 and 3, Page 4

The Charcoal Briquet Institute observes that paragraphs two and three on page 4 appear to set forth absolutes when, in fact reliable data were not available to Monsanto Research Corporation.

Paragraph 1, Page 17

The first complete sentence in this paragraph states:

> "This composition results in a briquet of approximately 90% pyrolysis product. A 90% charcoal briquet was assumed for this report."

At the meeting held August 31, 1977, the Charcoal Briquet Institute informed Monsanto Research Corporation staff that the total amount of carbonaceous material that is subjected to pyrolysis before mixing and briquetting now accounts for approximately 35% to 40% of the total product mix in the United States. A sizable tonnage of charcoal briquets is produced with virtually no carbonaceous material previously subjected to pyrolysis. A very small tonnage, possibly 5% of the total charcoal briquet production in the United States, can be classified as all wood charcoal.

Industry Status, Page 17

The report indicates here that:

> "The most recent thorough investigation of the industry was conducted by the U.S. Department of Agriculture Forest Service Division of Forest Economics and Marketing Research in 1961."

The Institute emphasizes that references used by Monsanto Research Corporation in evaluating and characterizing the industry in 1977 are based upon reports issued early in the history of the industry.

The USDA study, for example, characterizes an industry that is substantially different than the industry as we know it in 1977. There have been major changes in production patterns geographically. Manufacturing technology and equipment has drastically changed since 1961.

Such data are not qualified as an accurate source of background for making assumptions or making technical projections and forecasts in 1977.

Source Population, Paragraph 2, Page 18

Again, the report makes assumptions that 90% of each briquet is charcoal. The Institute emphasizes again that carbonaceous material subjected to pyrolysis comprises approximately 35% to 40% of all materials not entering the charcoal briquet materials mix.

Table 7, Page 20

Table 7 supplies the statistical data on geographical distribution on charcoal manufacturers. The Charcoal Briquet Institute maintains records for charcoal briquet manufacturers only. Data for Table 7 are supplied as follows:

State	Number of producers Monsanto report	 CBI data
Alabama	3	1
Arkansas	16	4
California	3	1
Georgia	1	0
Illinois	1	0
Maryland	1	0
Mississippi	4	1
Missouri	85	4
New Jersey	1	0
Ohio	4	1
Oklahoma	5	0
Oregon	2	2
Tennessee	8	2
Texas	5	2
West Virginia	6	1

Characterization of Emissions, Page 21

This section states that over 200 products of wood pyrolysis have been identified and they are listed in Table 6, COMPOUNDS.

The Institute emphasizes that many of the compounds occur naturally in nature and during the process of charcoal manufacture, would have no deleterious effect upon atmospheric or effluent discharges. Many of the compounds would not be emitted in the usual sense and would not affect the atmosphere, nor would they be considered an air pollutant.

Paragraphs 1 and 2, Pages 21 - 22

The Institute highlights these statements made in paragraphs one and two on pages 21 - 22:

> "Similarly, particulate emissions from briquetting operations have also been estimated, in the literature."
>
> "Very few data are available to characterize emissions from charcoal manufacture."
>
> "Most estimates found in the literature derive from material-balance calculations based on laboratory wood pyrolysis studies."
>
> "When reported, even field-sampling data from "Missouri-type" kilns are of questionable utility due to the improvisational sampling techniques utilized."

Potential Environmental Effects, Page 23

Since all of the emission data in the MRC report are based upon invalid assumptions and obsolete references, none of the suppositions and data set forth in this chapter can be considered of a useful nature.

Exact location of charcoal producing units has not been determined. The amount of controlled and uncontrolled emissions has not been determined. Therefore, it is impossible to evaluate environmental effects of charcoal production.

Both of the study methods offered by MRC on pages 24 and 25 cannot be utilized in this report since no valid base data are available.

Once again the Institute emphasizes that Tables 8, 9, 10, and 11 should not be recognized since the data are grossly inaccurate.

Likewise, the Institute highlights the statement made in the second paragraph on page 22:

> "The accuracy of the emission estimates is uncertain at best."

Table 8, Page 22

The inclusion of tar, oil, and pyroacids under particulates and "higher hydrocarbons" under other gases results in double accounting. "Higher hydrocarbons" are undefined. Tar, oil, pyroacids, and "higher hydrocarbons" are converted into harmless carbon dioxide and water by incineration. Charcoal production emits substantially no pollution in the form of NO_x.

Final Paragraph, Page 25

The report states that:

> "The potential environmental impact of emissions from charcoal manufacture can also be evaluated by comparing the nationwide mass of each criteria emission from charcoal production to the total nationwide mass of each criteria emission from all sources."

The Charcoal Briquet Institute seriously questions this assumption because statements made elsewhere in the MRC report refute this possibility.

The Institute's position is further substantiated by this statement which appears in the same paragraph:

> "Actual national charcoal manufacture emissions cannot be calculated because of a lack of information regarding the application and efficiency of control technology."

Table 10, Page 27

The qualification that maximum estimates are used in Table 10 is not given in the table.

Table 10 data are not considered to be useful since a three-year time span separates "Estimated Charcoal Industry Emission" and "National Emissions for All Sources."

Paragraph 2, Page 27

Statements made in this paragraph which relate to particulate, carbon monoxide and emission of other gases are represented as accurate. Such suppositions should not be made because there are no reliable support data.

Table 11, Page 28

Brief, preliminary calculations by the Charcoal Briquet Institute indicate that Column 2, "Fraction of National Production," does not represent current data and is grossly inaccurate.

Therefore, all assumptions made in the columns appearing under "Estimated Controlled Criteria Emissions" are fallacious and should not be used.

References, Page 34

The Institute notes that references used in preparation of the Monsanto Report have been utilized as authoritative sources though many listings have aged and are not reliable as background information.

It is further noted that Monsanto Research Corporation in many cases elected not to recognize and use expert opinions offered by industry representatives.

Table A-1, Page 40

The Charcoal Briquet Institute is unable to verify the existence of many producers listed in Table A-1. Numerous companies have dual listings, some of the companies are no longer in business, and the annual production in metric tons is substantially overstated in some cases. The listing should not be utilized in assessing the industry position in any state until such time that an industry census has been developed.

Items 18 and 19, Distribution Statement, Page 77

The Distribution and Security Class for this report is entered as "Unlimited" and "Unclassified."

The Charcoal Briquet Institute recommends that the entire Monsanto Research Corporation report not be distributed and that the report remain classified within the Monsanto Research Corporation and the Environmental Protection Agency.

GLOSSARY

brands: Partially charred wood.

carbonaceous: Material containing carbon.

carbonization: Process of increasing the carbon content of a material by subjecting it to elevated temperatures to drive off volatile hydrocarbons.

cord: Quantity of wood stacked in a 4-ft x 4-ft x 8-ft pile, 128 ft^3 (3.63 m^3).

cordwood: Pieces of wood approximately 1.2 m long and 150 mm to 200 mm in diameter.

destructive distillation: Process of making charcoal by distilling off volatile hydrocarbons from carbonaceous materials.

hardwood: Wood of an angiospermous tree such as beech or oak.

hogged: Adjective describing wood that has been broken into small chips.

pyroligneous: Obtained from the destructive distillation of wood.

pyroligneous acid, pyroligneous liquor, pyroacid: Reddish brown acidic liquid produced by the destructive distillation of wood; the condensible water soluble products of destructive distillation of wood.

pyrolysis: Process of removing volatiles from a material by elevating the temperature with minimal oxygen present.

rabble arms: Device in a continuous furnace which rakes the raw material over each bed to expose fresh material to hot pyrolysis gases and to advance the material through the furnace.

softwood: Wood of a coniferous tree such as pine.